NASA-CR-201001

Final Report
Attachment 8

October 17, 1995

CONTRACT NAS8-38856

Structural Damage Prediction and Analysis for Hypervelocity Impact

UDRI Light Gas Gun Test Data Summaries

Prepared for:
National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center,
Alabama 35812

LOCKHEED MARTIN

UDRI LIGHT GAS GUN TEST DATA SUMMARIES

FOREWORD

The Hypervelocity Light Gas gun testing was performed under contract NAS8-38856 from NASA Marshall Space Flight Center (MSFC). These tests were performed at the University of Dayton Research Institute (UDRI) under subcontract from Lockheed Martin Manned Space Systems. The UDRI Program Manager was Mr. Andrew Piekutowski. Specimens, glossy photographs, and test records were sent directly to the NASA/MSFC Technical Representative. Copies of the photographs and test records are included here as part of the contract final report.

The study contract (NAS8-38856) title was "Structural Damage Prediction and Analysis for Hypervelocity Impacts." The Technical Representatives were Dr. Joel Williamsen, Mr. Greg Olsen, and Ms. Jennifer Robinson. The testing was performed between October, 1990 and September, 1995.

RESULTS OF TESTS WITH HEX BUMPER

The HEX bumper was originally developed for use with the Defensive Shields Demonstration (DSD) Program. The University of Dayton Research Institute was a subcontractor to the Martin Marietta Astronautics Group in Denver Colorado at the time the HEX bumper was designed for use on the DSD Program. The design originated at the University and was essentially made available to interested parties. All HEX bumpers used in the DSD Program were fabricated at the University by rolling sheet stock through a special set of rollers. Two pieces of 3003-H14 aluminum sheet were rolled to produce the bumpers evaluated in Shots 4-1302 and 4-1304. A brief summary of the results of these tests is given in below. Contact prints of the multiple-exposure, orthogonal view radiographs of the debris clouds produced by the tests are attached. A sketch of the HEX bumper design is also attached.

TEST DESCRIPTION AND RESULTS

Shot 4-1302

Projectile:	9.53-mm-diameter, 2017-T4 aluminum sphere. Mass = 1.2754 g
Impact Velocity:	6.68 km/s
Target:	3003-H14 Aluminum HEX, Equivalent thickness of a flat sheet = 0.0455 inches. The bumper sheet was installed at a 45 degree angle to the shot line for the test. A 3.18-mm-thick, 5456-H116 aluminum witness plate was placed 14.75 inches behind and parallel to the bumper sheet.
X-Ray Times:	Approx. 1.5 μs before impact and 8.9, 24.8, and 47.4 μs after impact

Shot 4-1304

Projectile:	9.53-mm-diameter, 2017-T4 aluminum sphere. Mass = 1.2751 g
Impact Velocity:	6.78 km/s
Target:	3003-H14 Aluminum HEX, Equivalent thickness of a flat sheet = 0.0455 inches. The bumper sheet was installed normal to the shot line for the test. A 3.18-mm-thick, 2219-T87 aluminum witness plate was placed 14.50 inches behind and parallel to the bumper sheet.
X-Ray Times:	Approx. 2.0 μs before impact and 8.4, 24.2, and 46.9 μs after impact

TABLE OF CONTENTS

Foreword i
Table of Contents ii
Hex Bumper Tests 1
Pressure Wall Debris Tests 7
Hole Size (Cadmium / Aluminum) Tests 55

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INTRODUCING . . .

THE "HEX"

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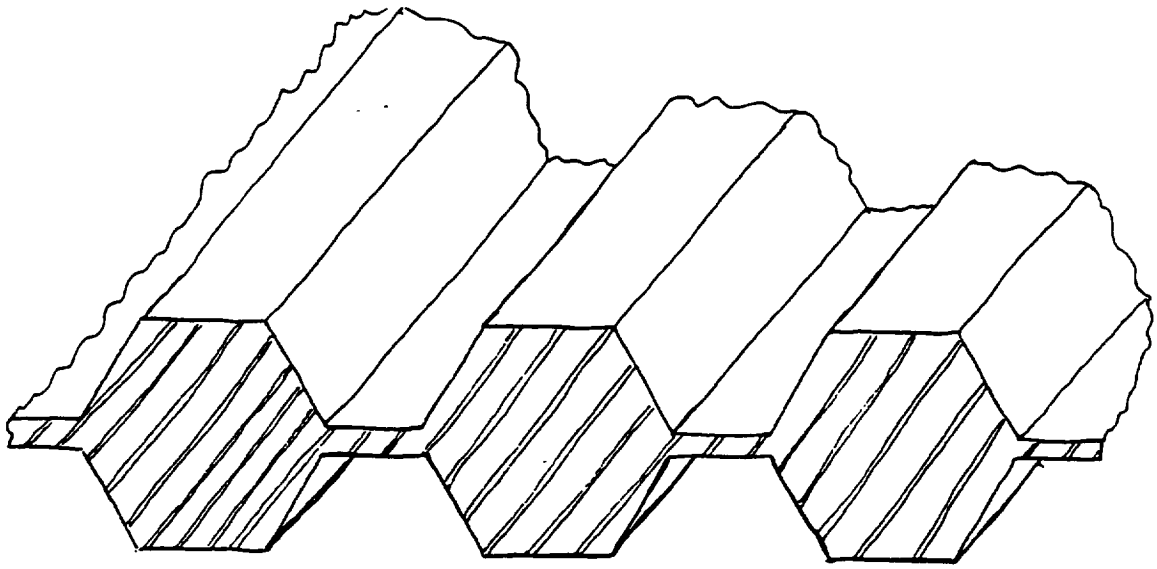

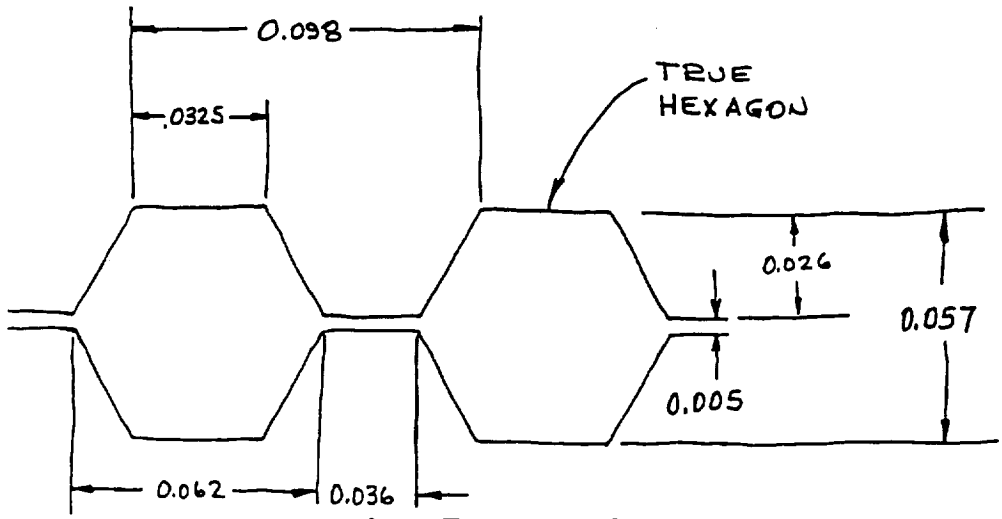

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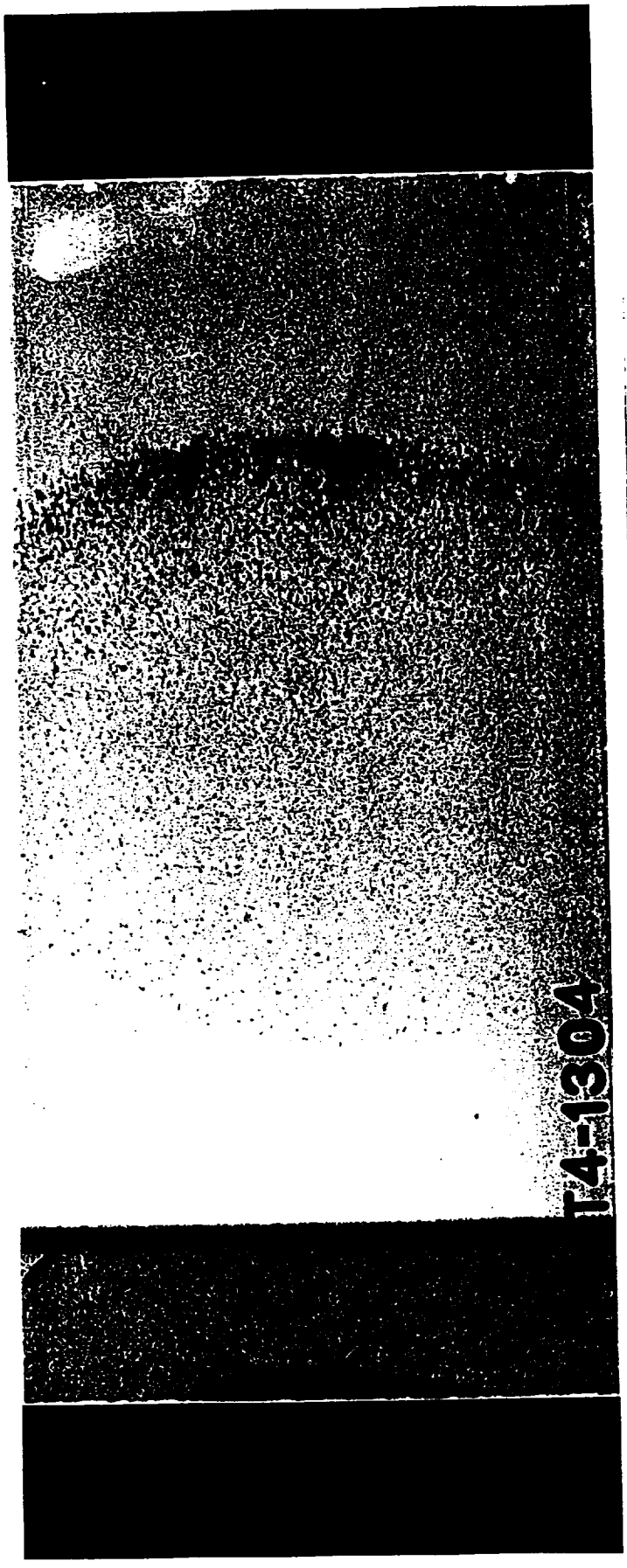

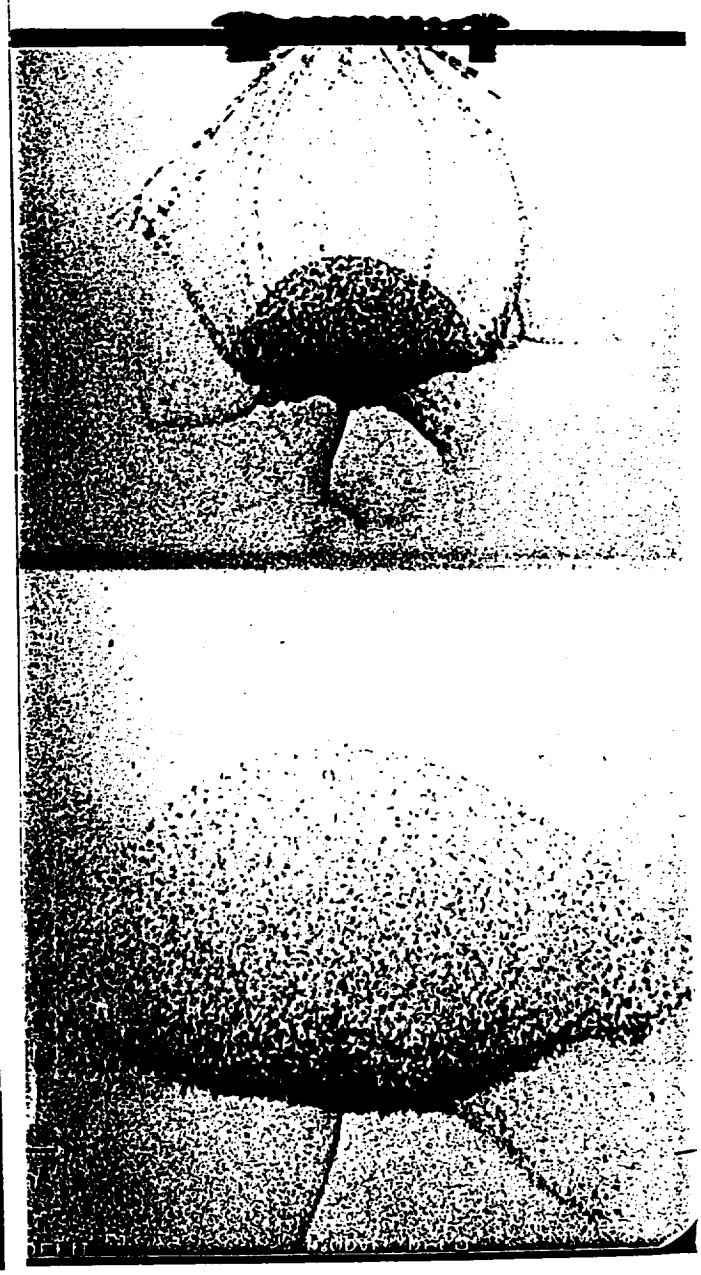

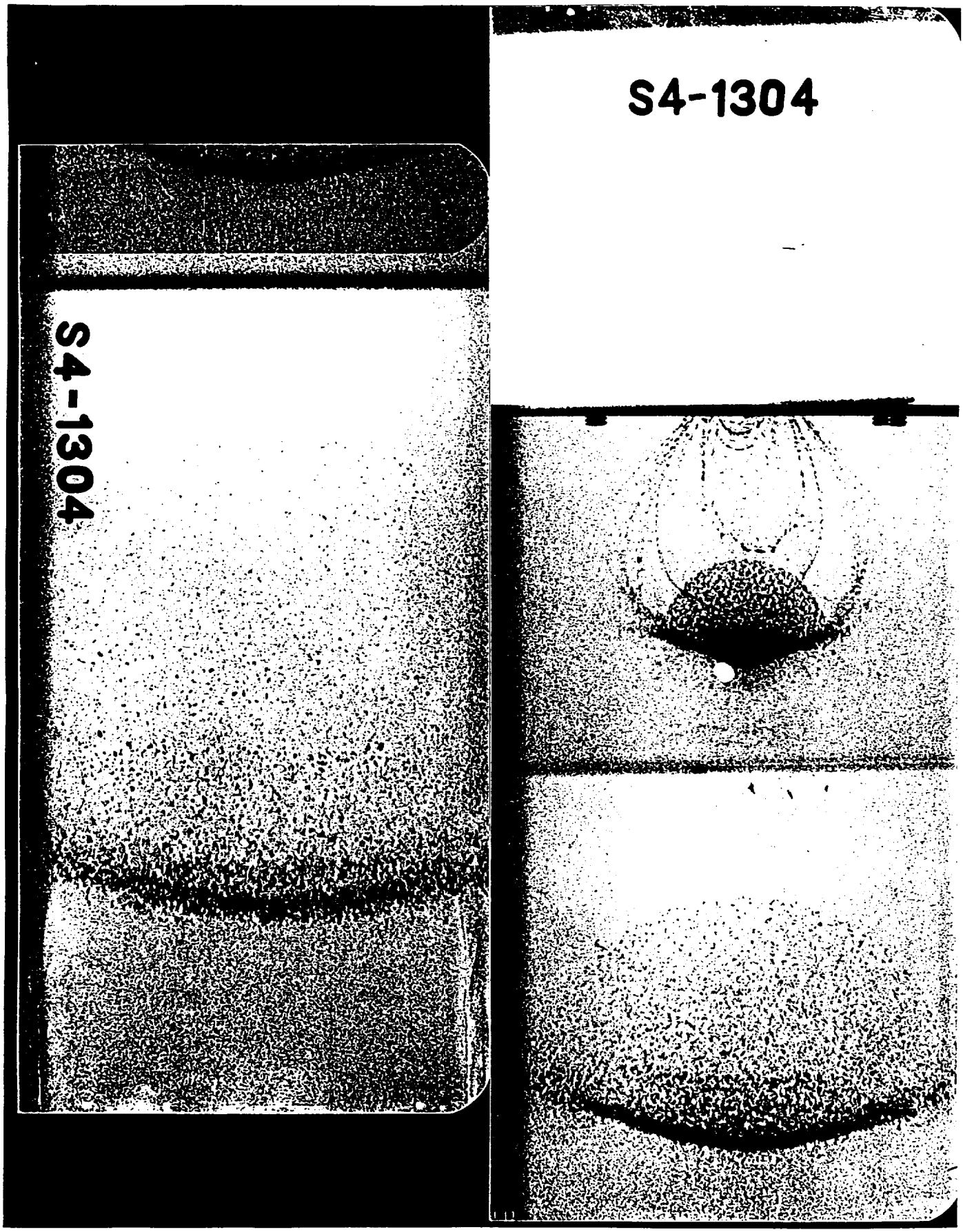
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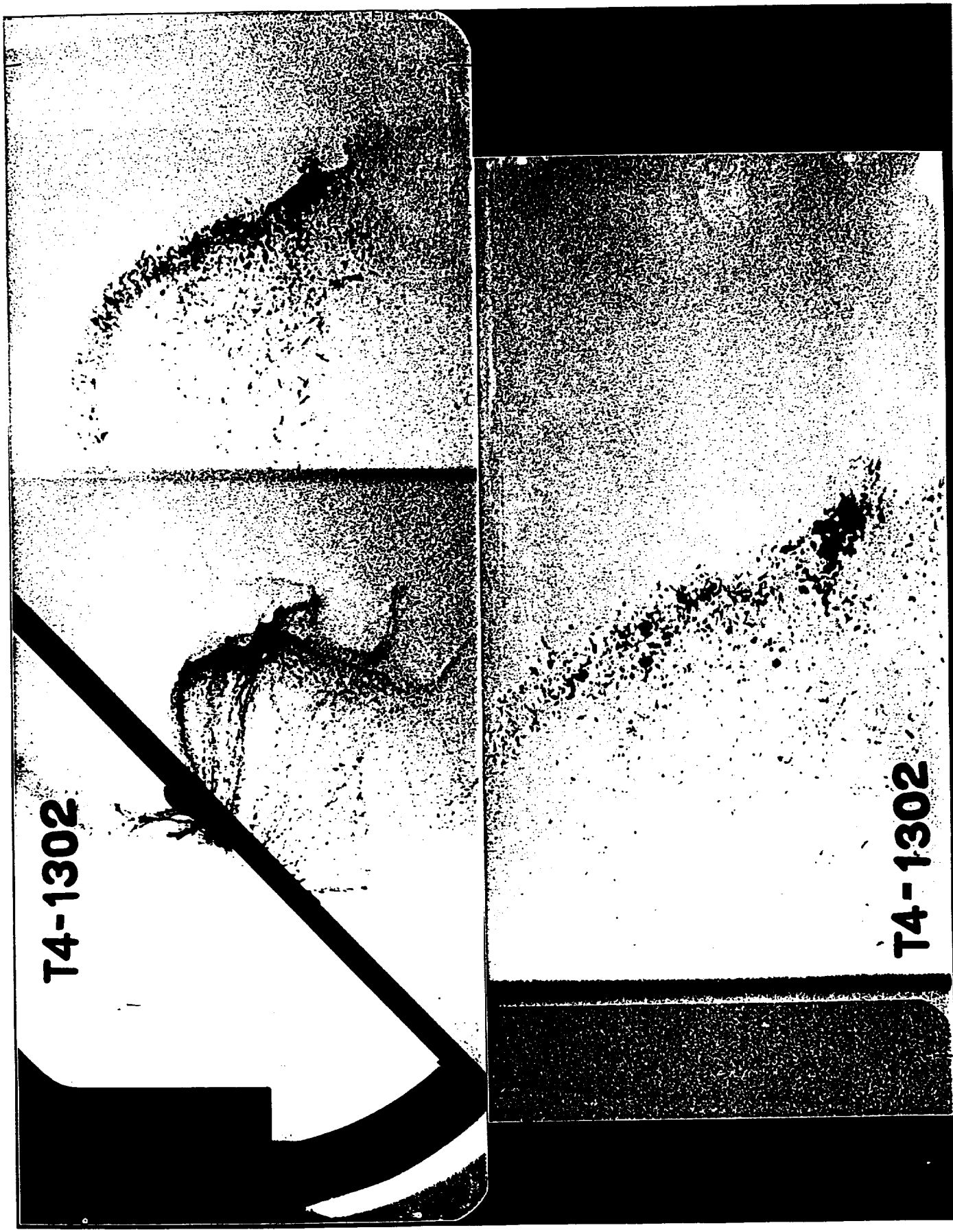
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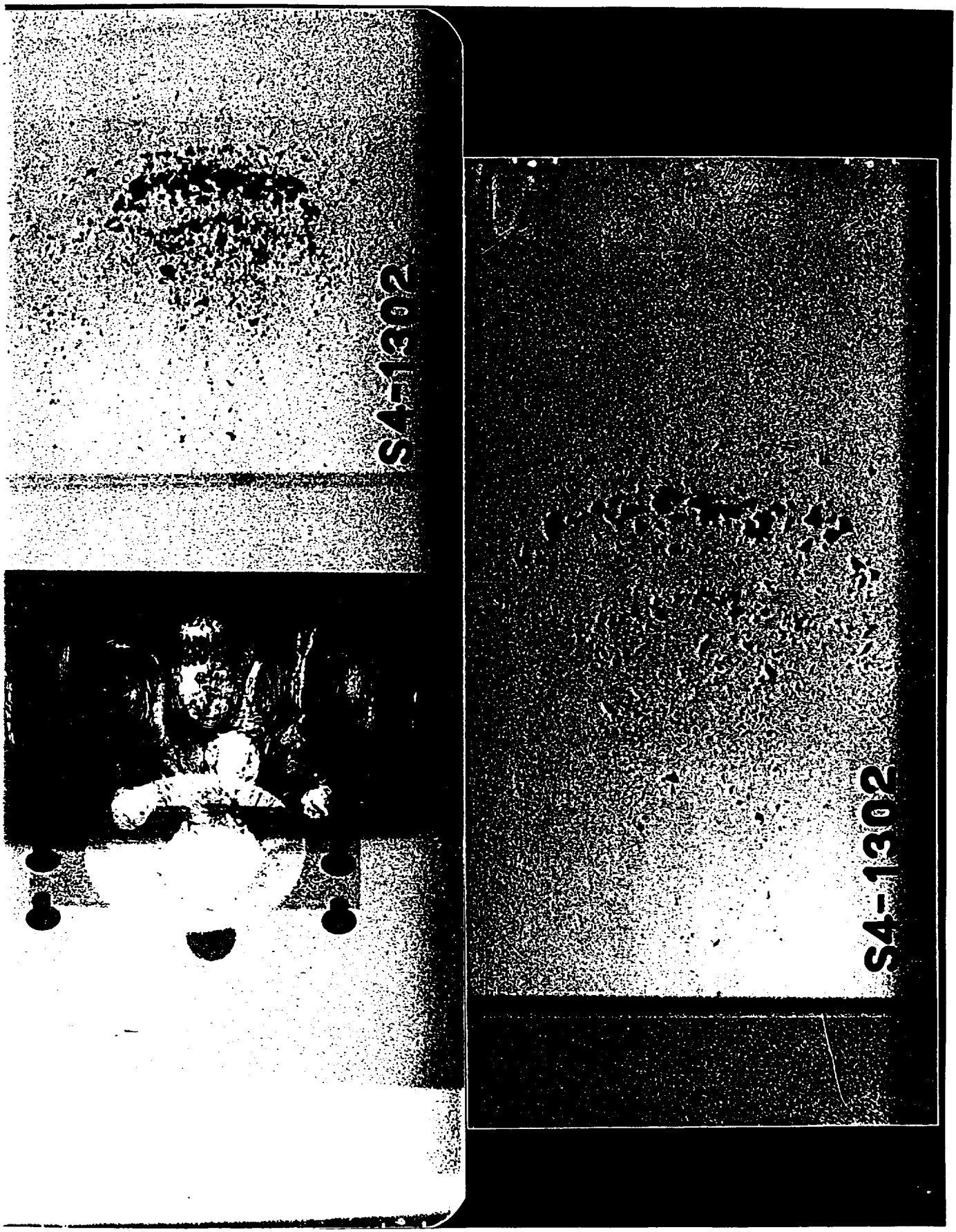
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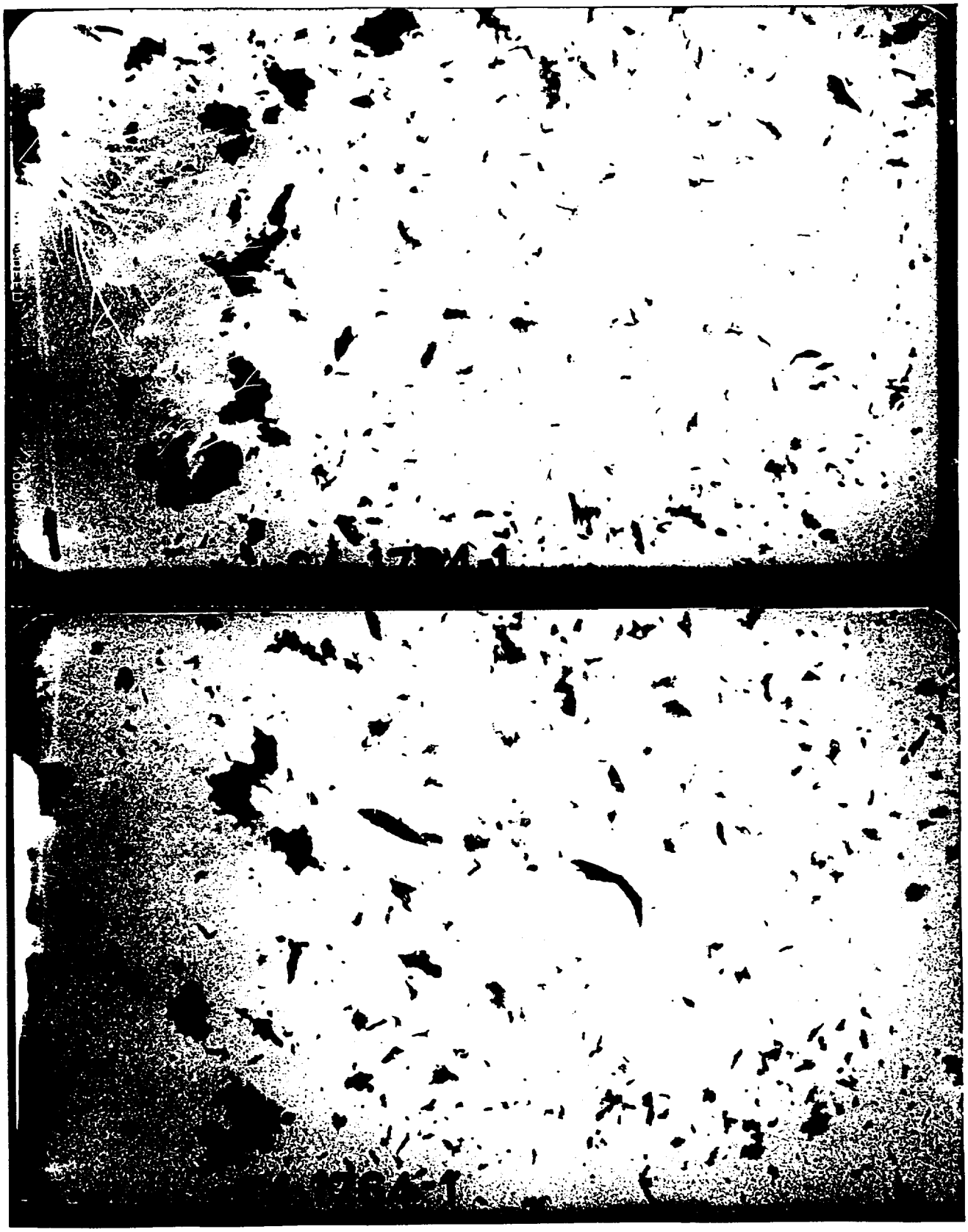
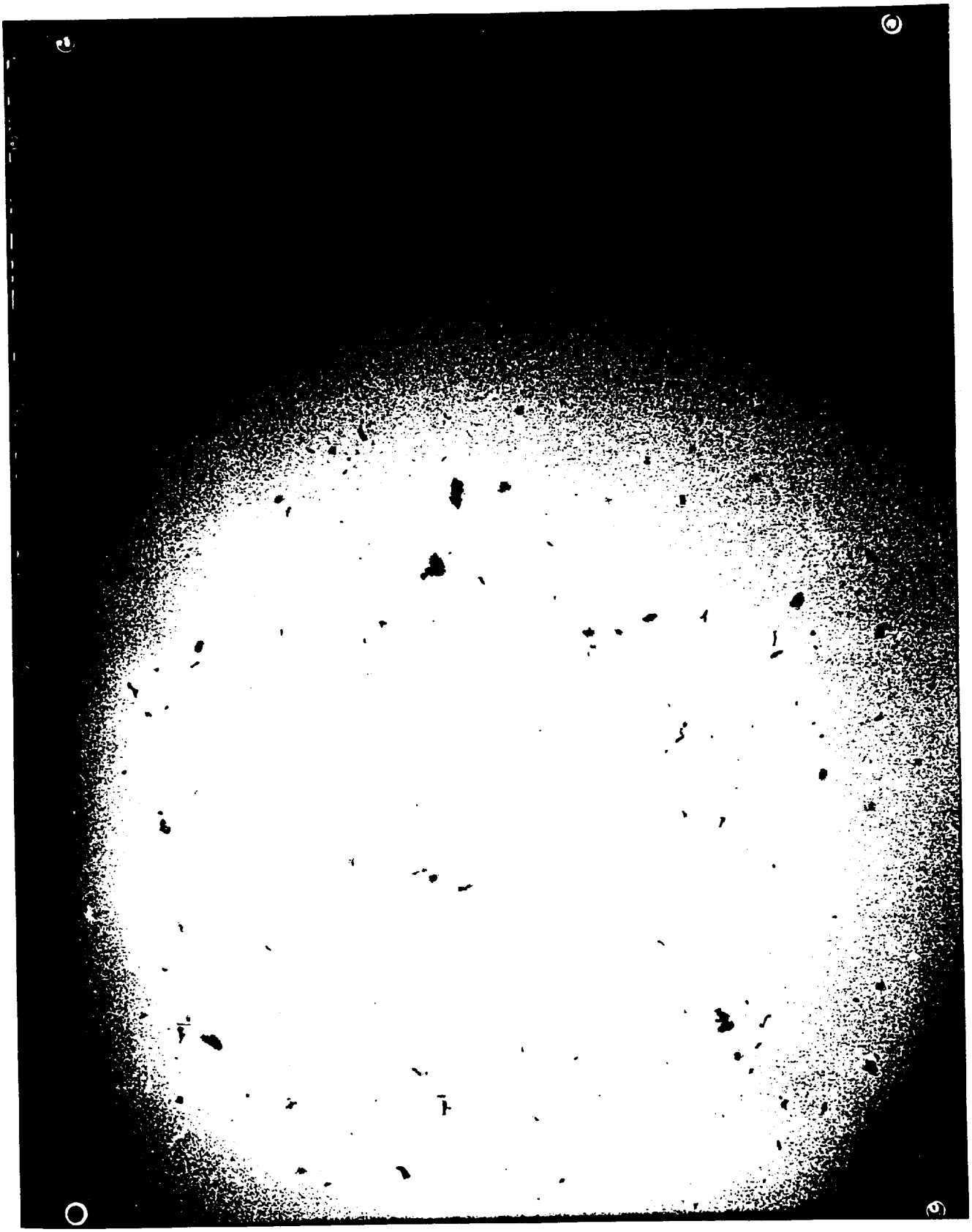
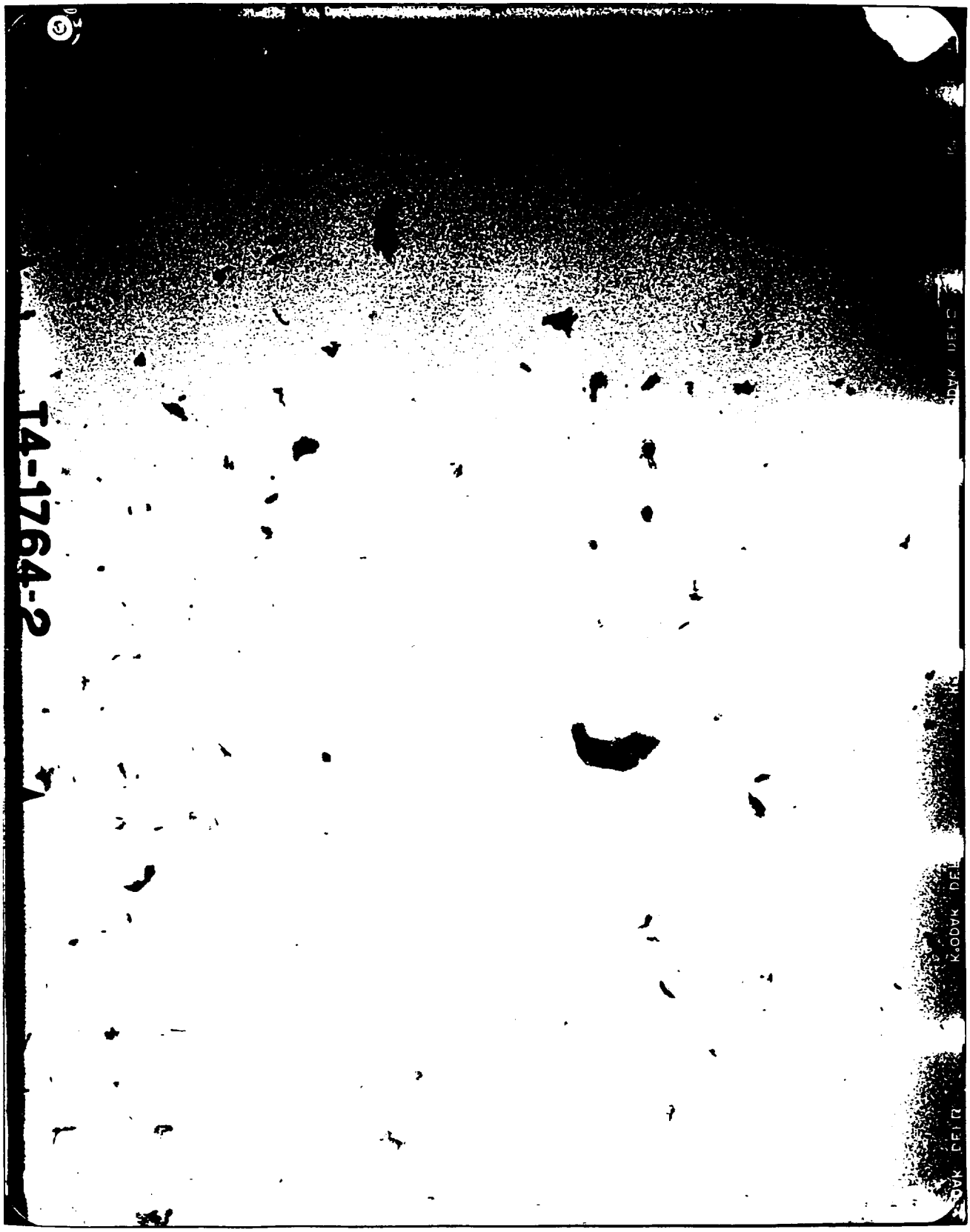
MANNED MODULE PRESSURE WALL DEBRIS CHARACTERIZATION TEST SUMMARY

Shot Number	4-1764	4-1765	4-1766	4-1767	4-1768	4-1769	4-1770	4-1771
				TEST CONDITIONS				
Test-Chamber Pressure (Air)	12 mm	12 mm	12 mm	1 Atm	12 mm	1 Atm	1 Atm	12 mm
Sphere Diameter (Inches)	0.500	0.500	0.625	0.625	0.625	0.500	0.500	0.500
Measured Impact Velocity (km/s)	6.34	6.30	6.12	6.18	6.18	6.50	6.44	6.45
				SETUP CONDITIONS FOR X-RAYS				
Nominal Impact Velocity (km/s)	6.30	6.30	6.20	6.20	6.20	6.50	6.50	6.50
Ratio of Expected Velocity of Leading Edge of Debris to Nominal Velocity of Sphere	0.14	0.14	0.60	0.45	0.25	0.35	0.55	0.55
Nominal Position of Leading Edge of Debris w/r to Main Fiducial[a]								
View 1	1.5	0	0.5	1.0	0.5	1.0	0.5	1.0
View 2	2.0	0.5	0.5	1.0	0.5	1.0	0.5	1.0
View 3	2.0	0	0	1.0	1.0	1.0	0.5	1.0
				MEASURED TIME BETWEEN X-RAY EXPOSURES				
Pre-Impact to View 1 (μs)	395.8[b]	358.6	234.3	253.6	296.4	259.3	227.3	230.8
View 1 to View 2 (μs)	300.3	300.2	68.2	90.9	163.8	111.5	71.0	71.1
View 2 to View 3 (μs)	286.0	271.8	65.0	91.3	172.1	111.7	71.1	71.2
				LEADING-EDGE-FRAGMENT SIZE AND VELOCITY				
Fragment Height--Side view (Inches)								
Fragment Width--Top View (Inches)								
Velocity, View 1 to View 2 (km/s)								
Velocity, View 2 to View 3 (km/s)								

[a] Positive values are distance downrange of main fiducial; negative values are distance uprange of main fiducial.
[b] Used foil switch on front of rear wall to trigger x-rays for Views 1, 2, and 3. Switch triggered about 4 μs early.



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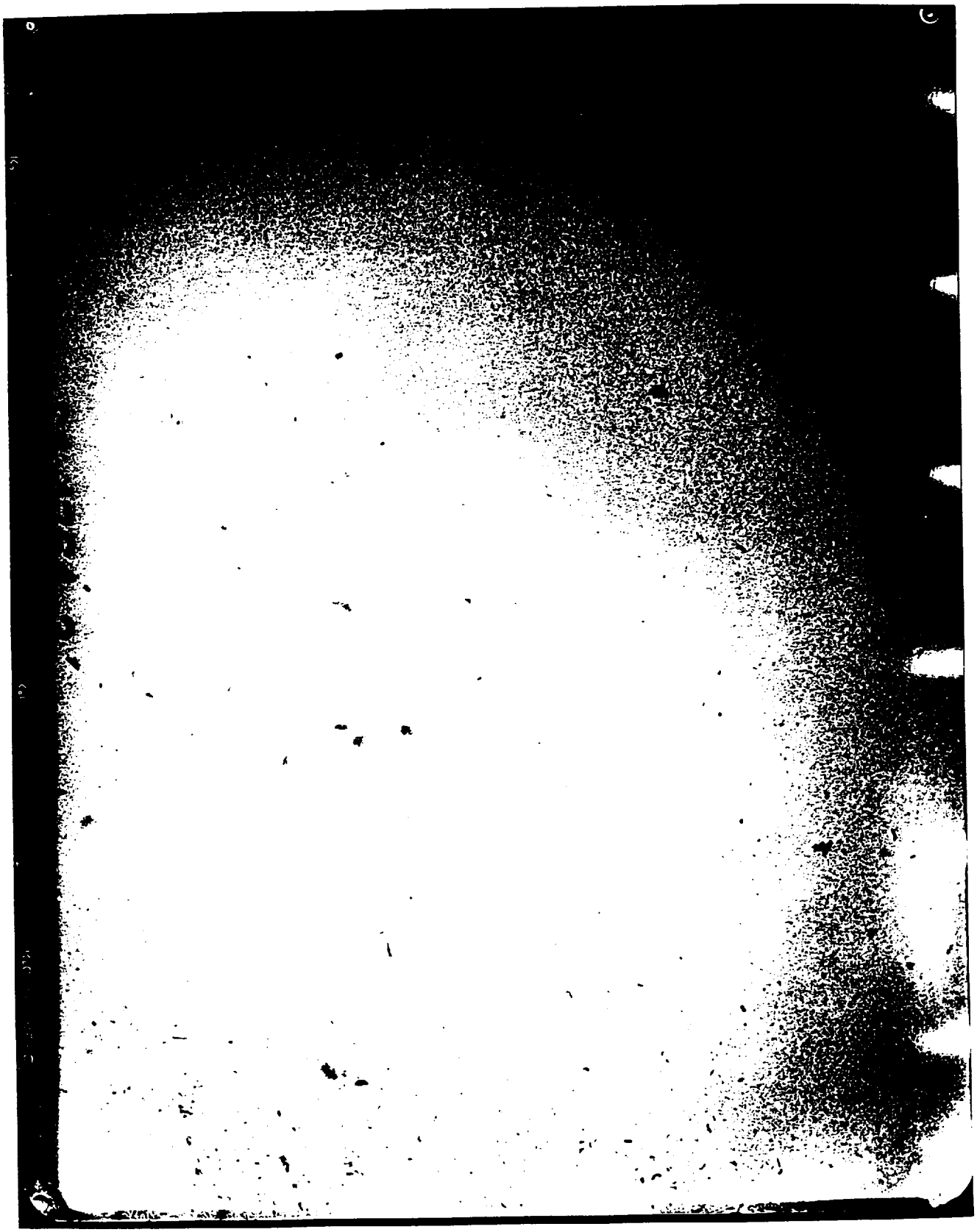

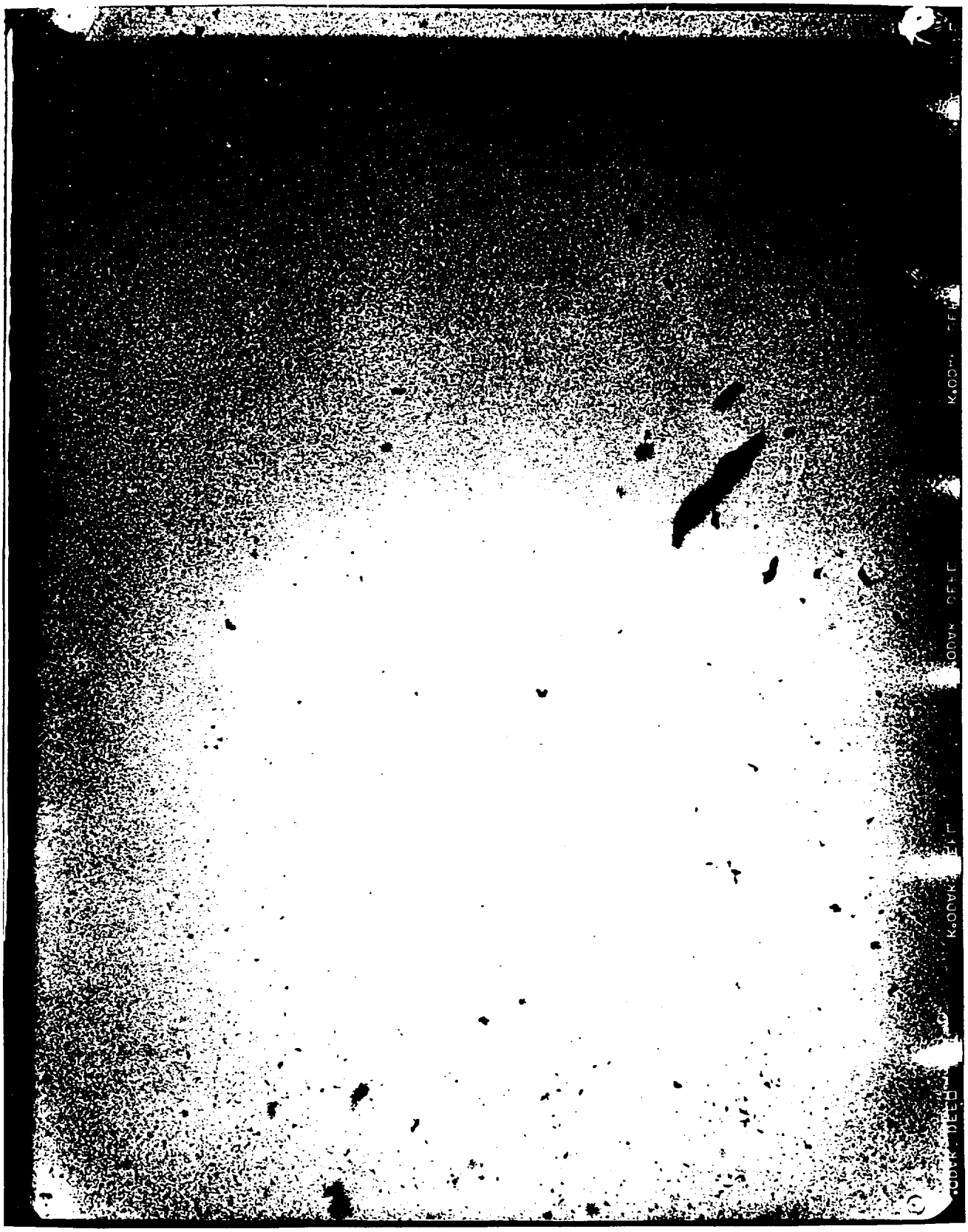

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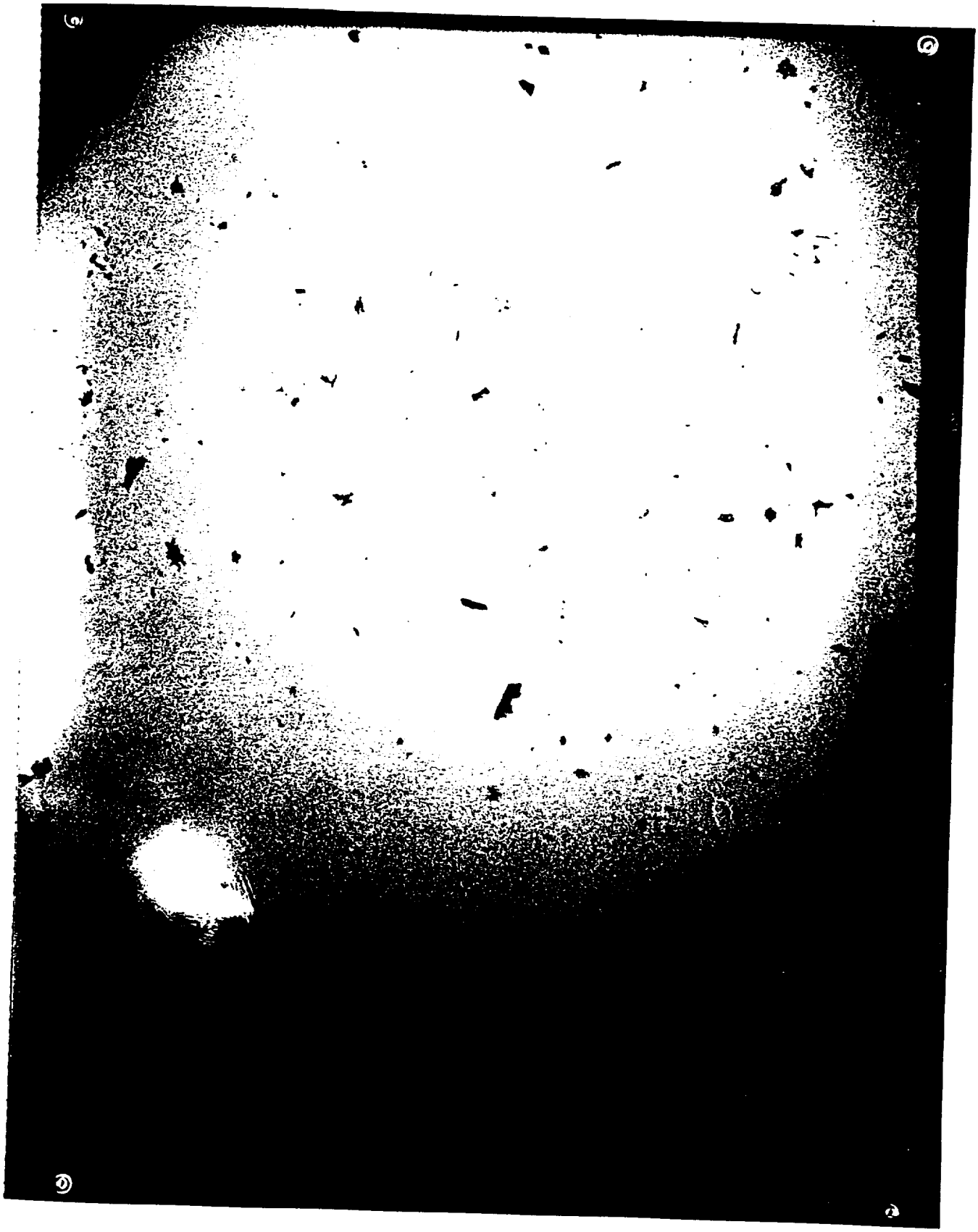

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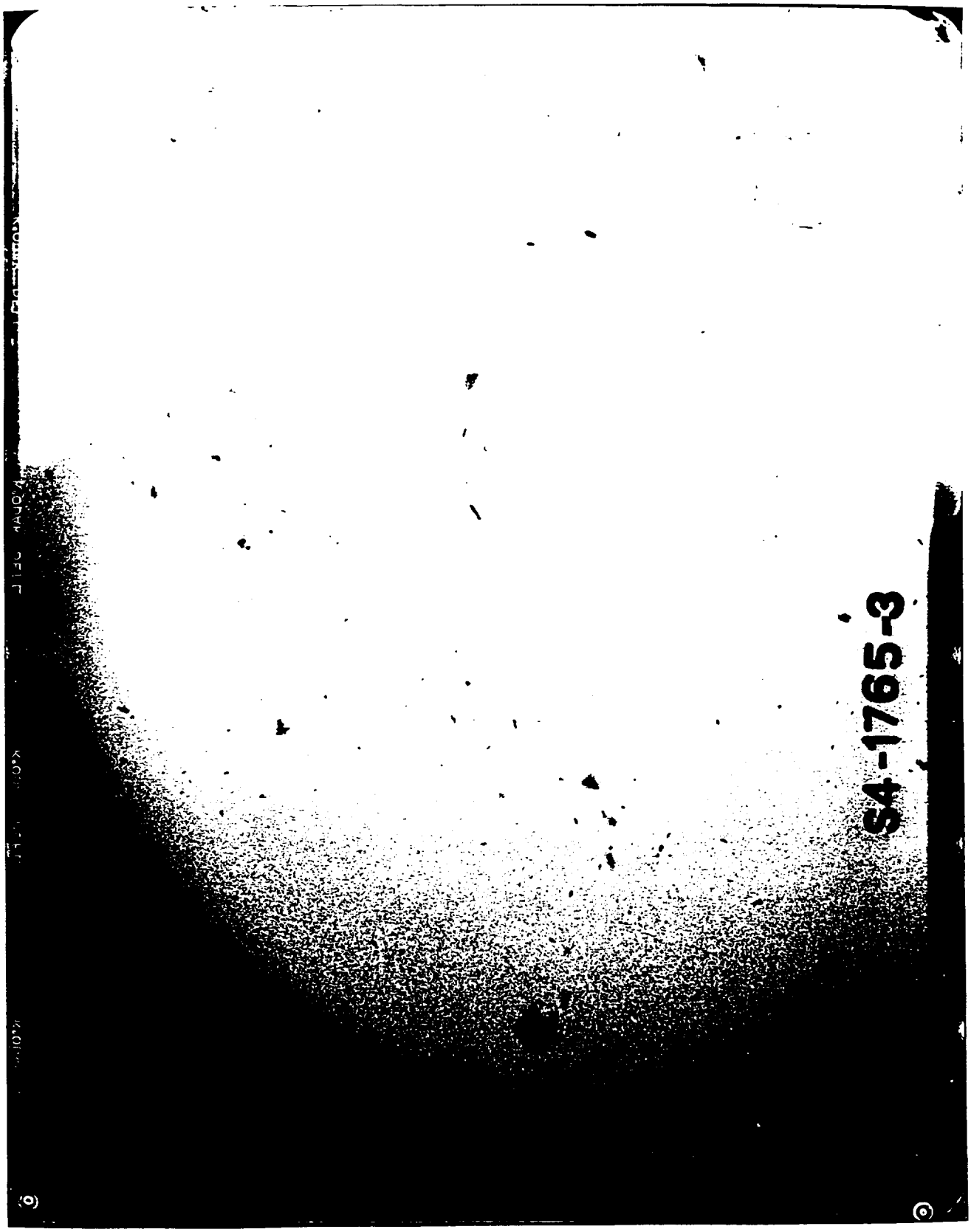
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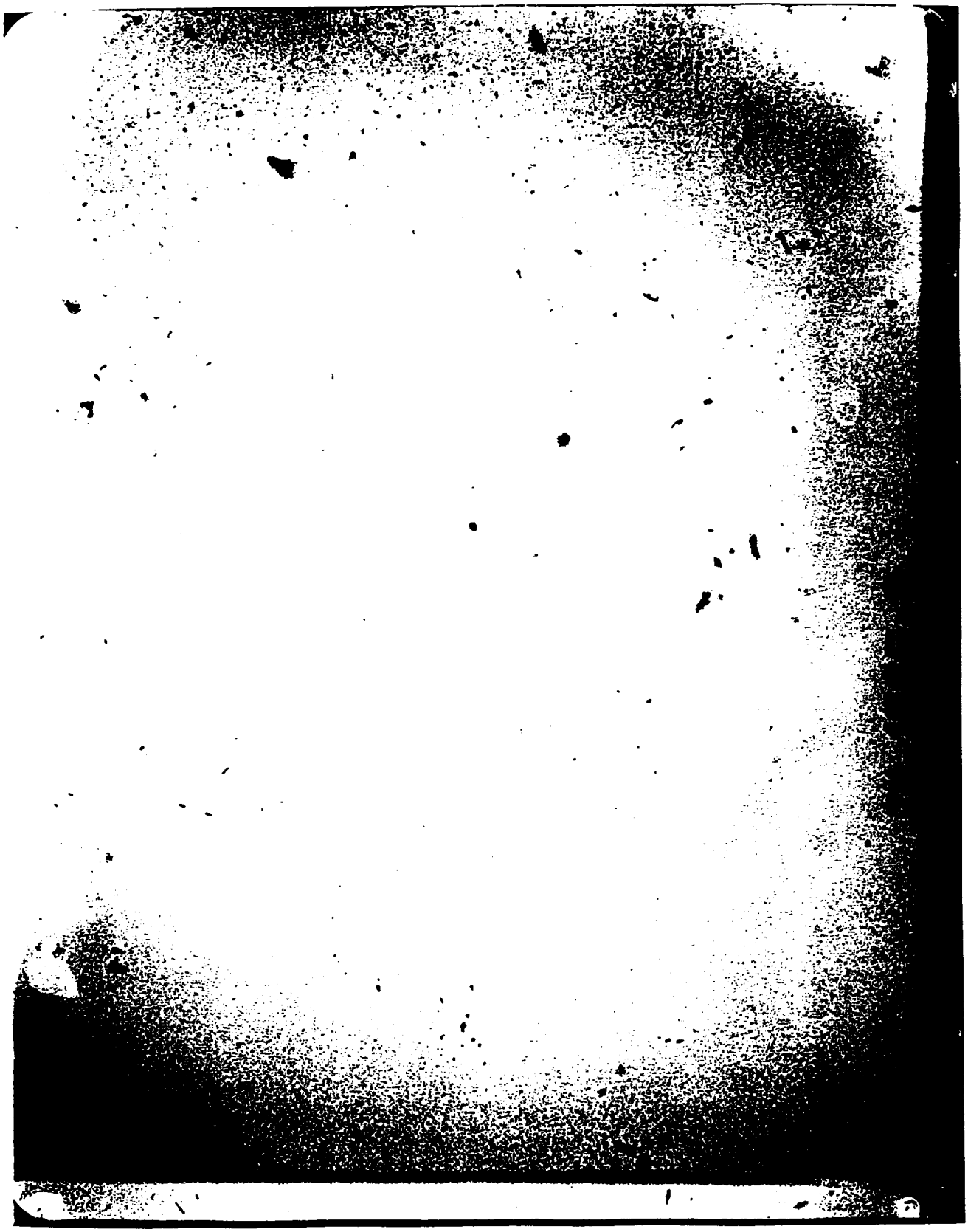

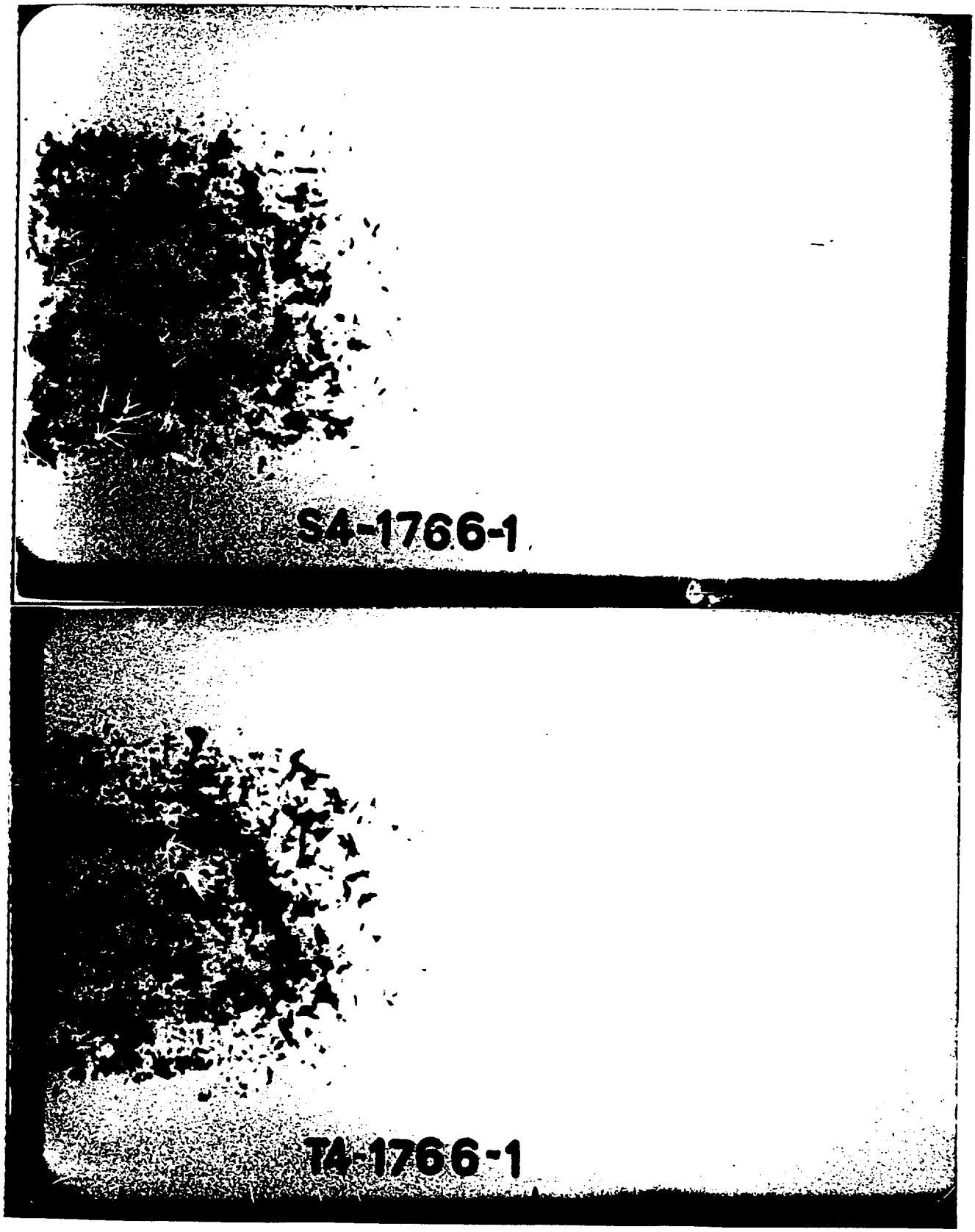
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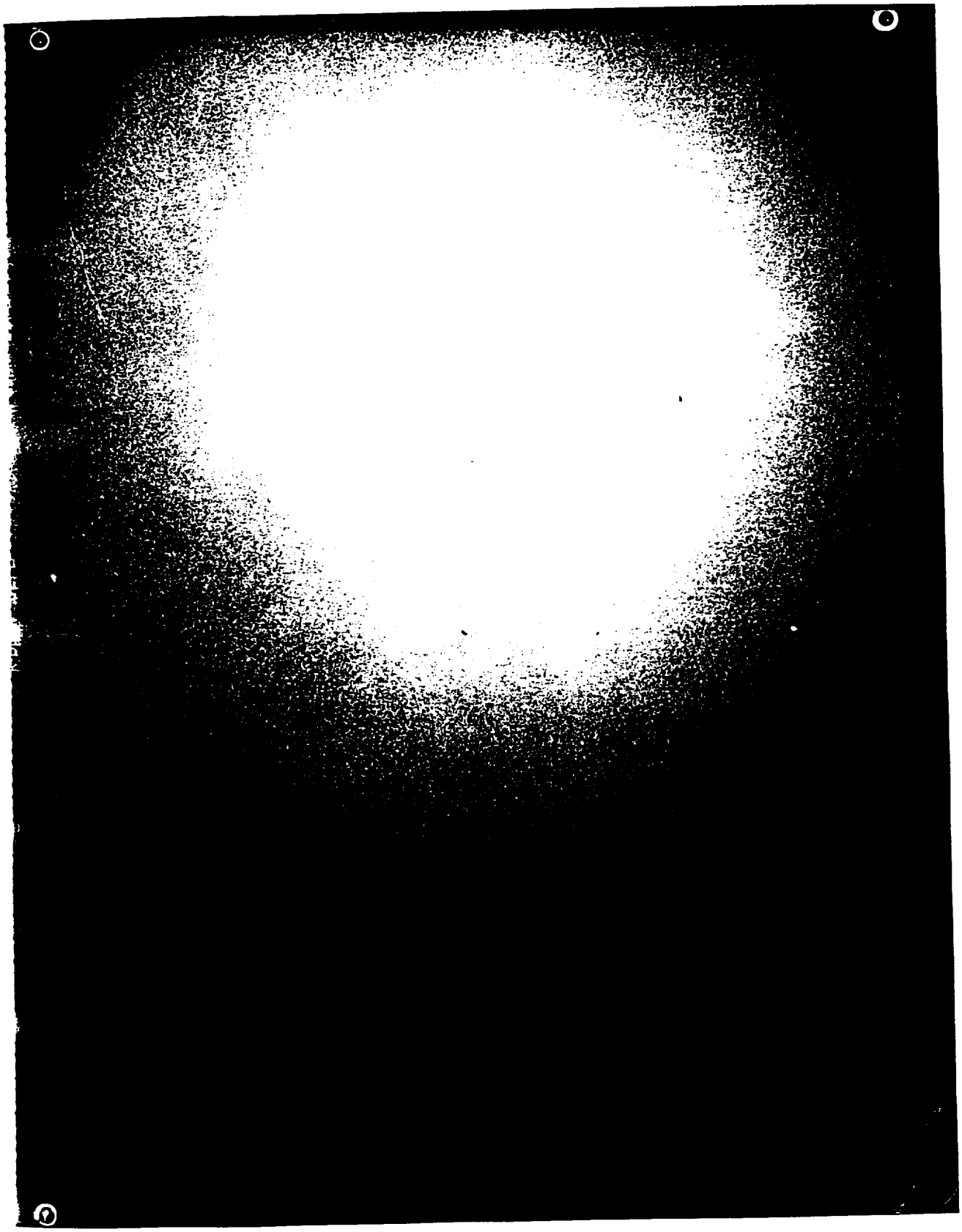

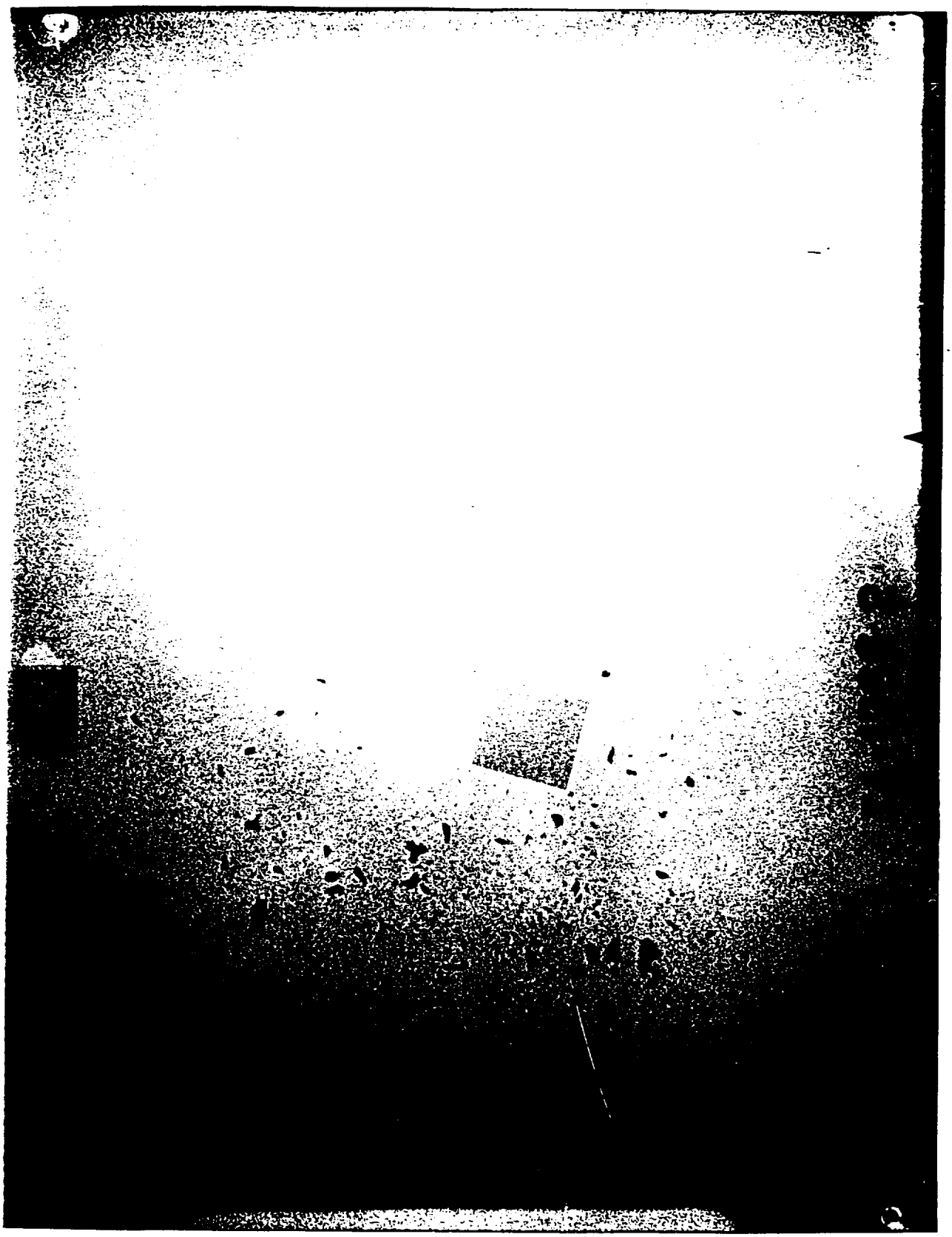

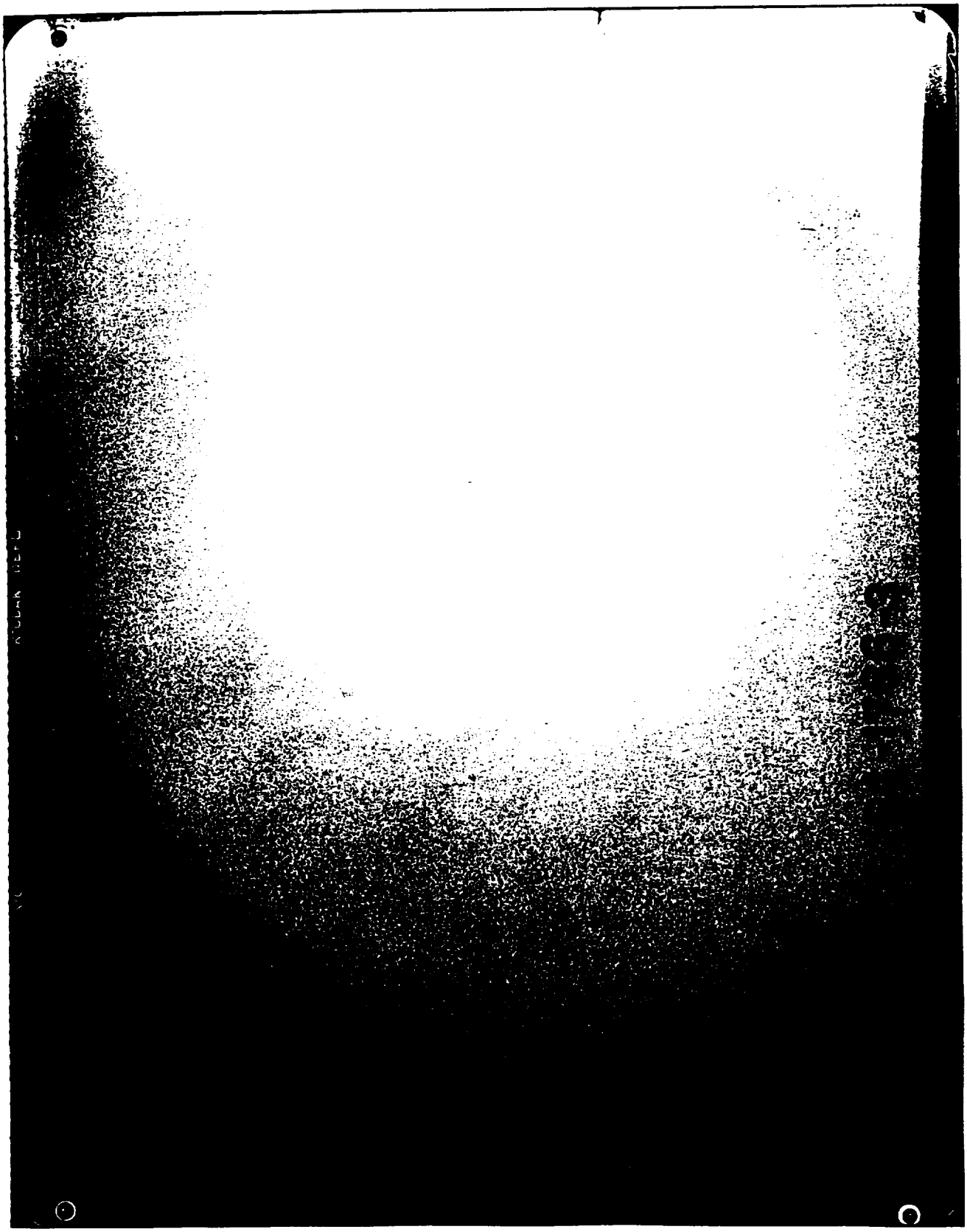

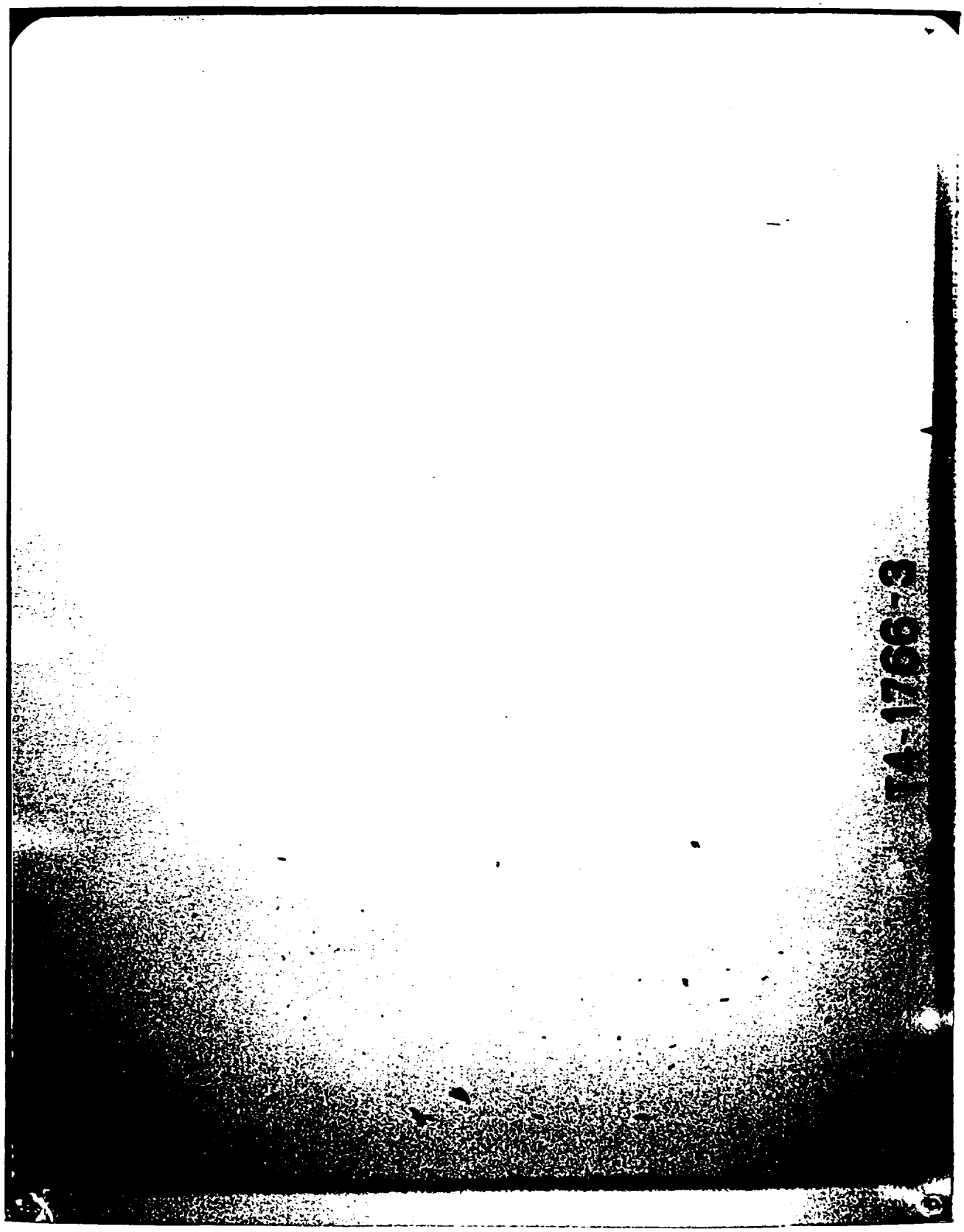
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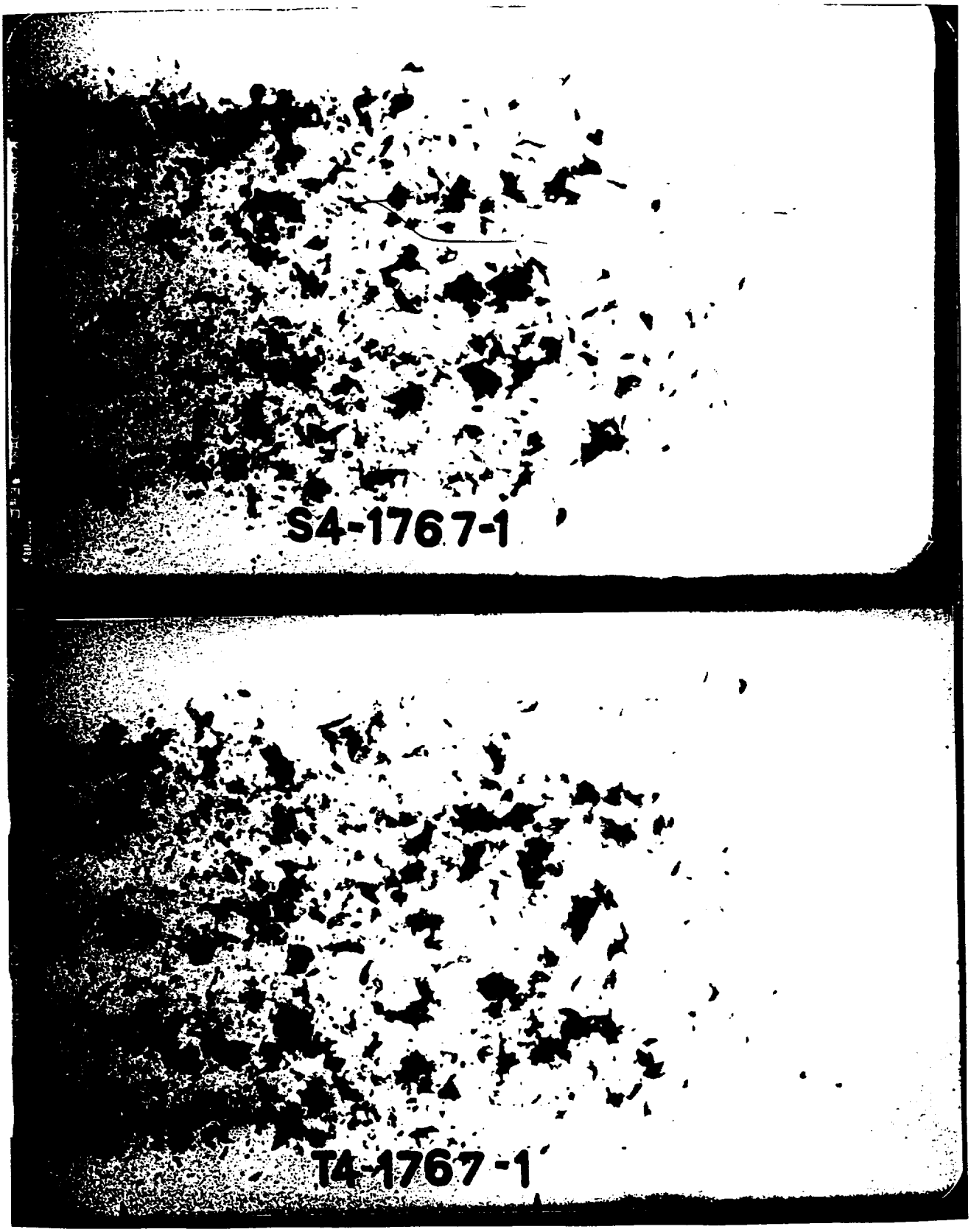
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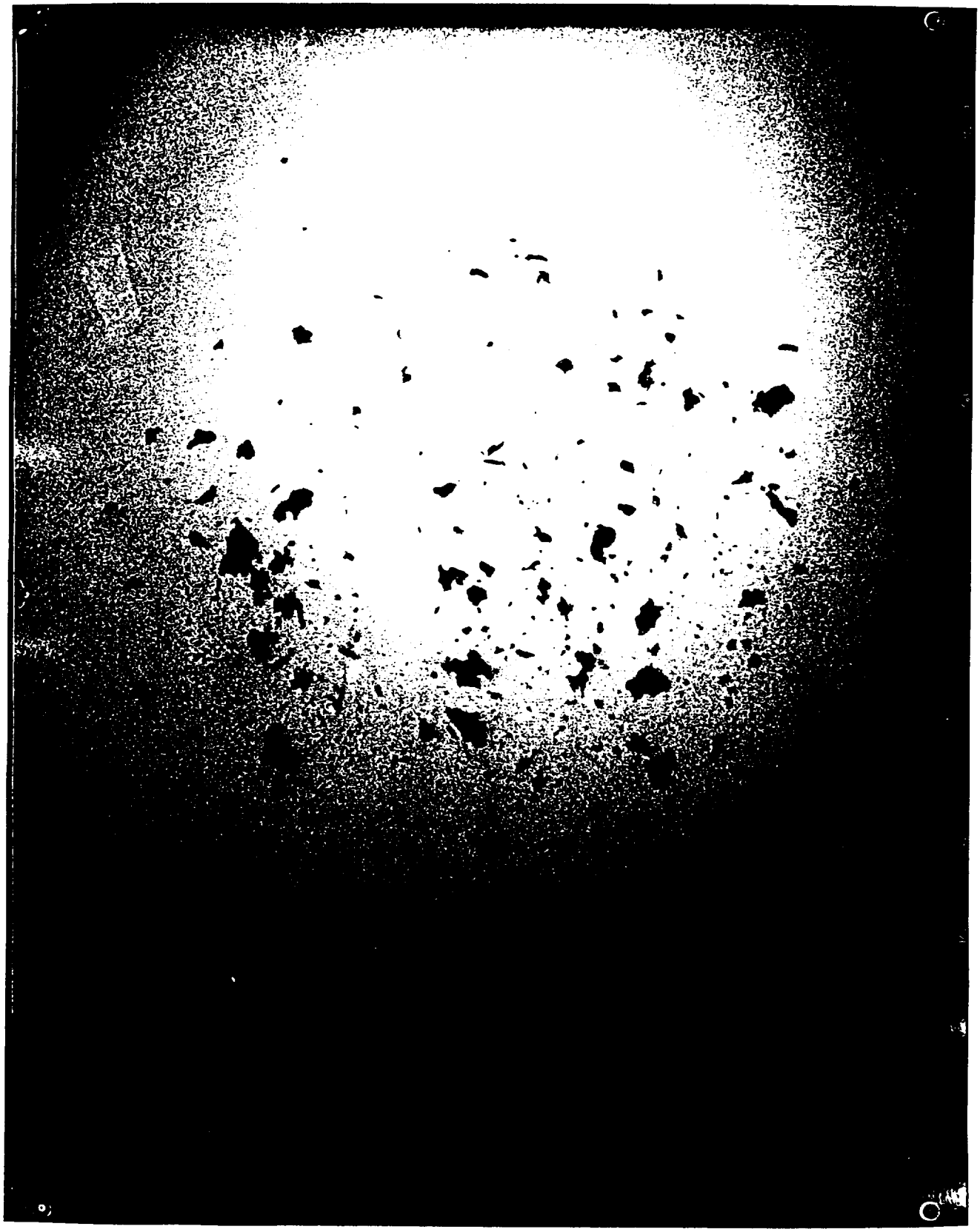

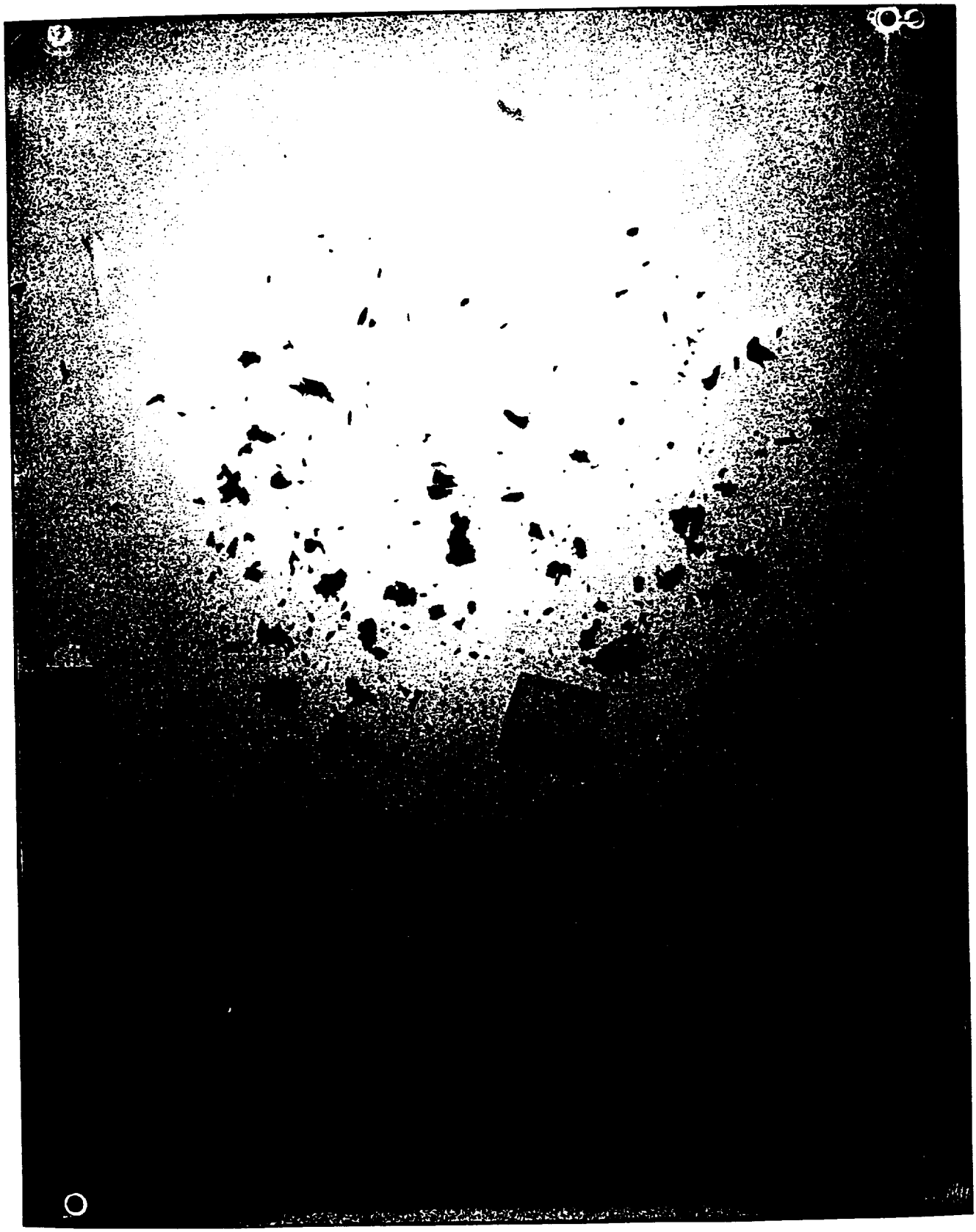

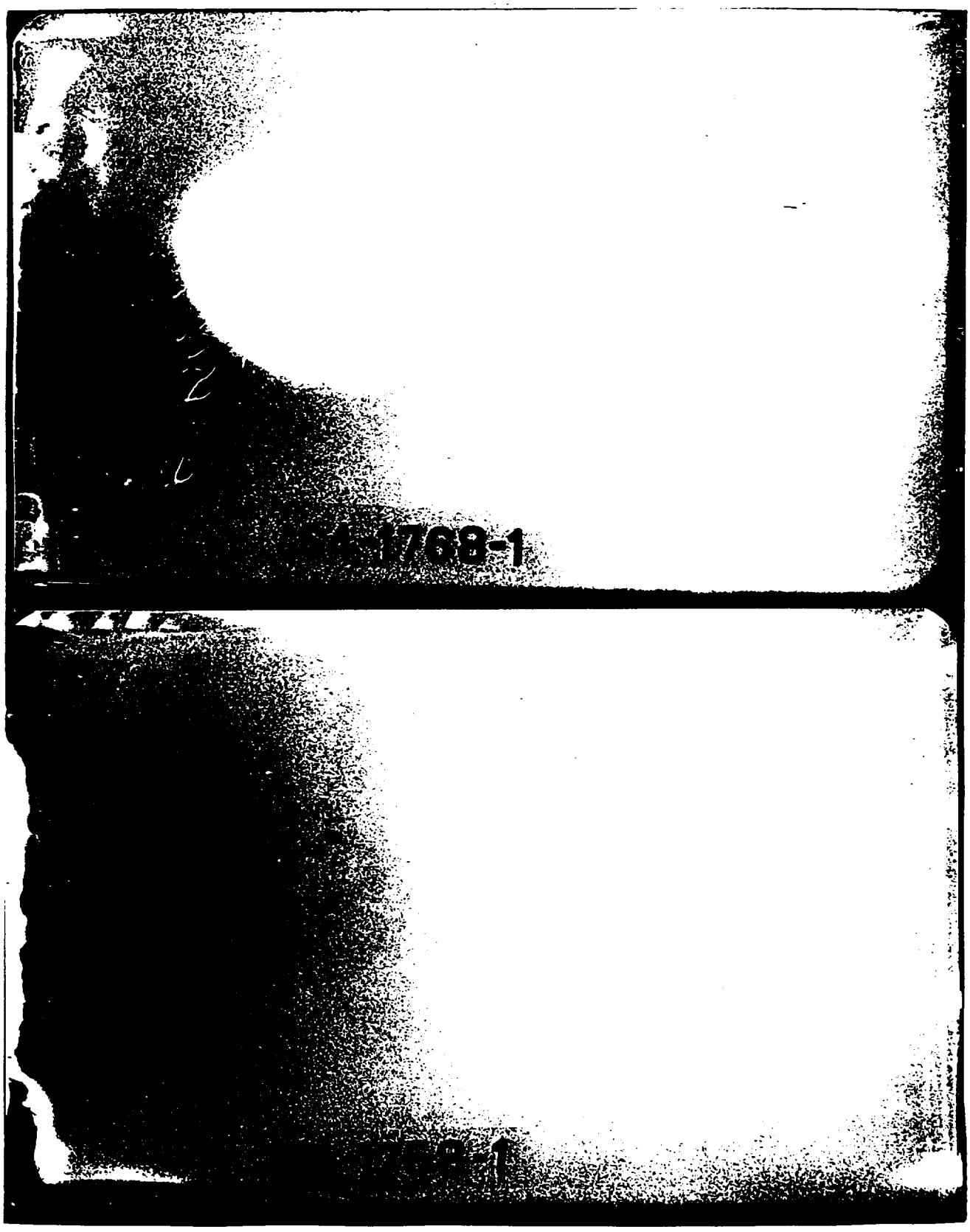
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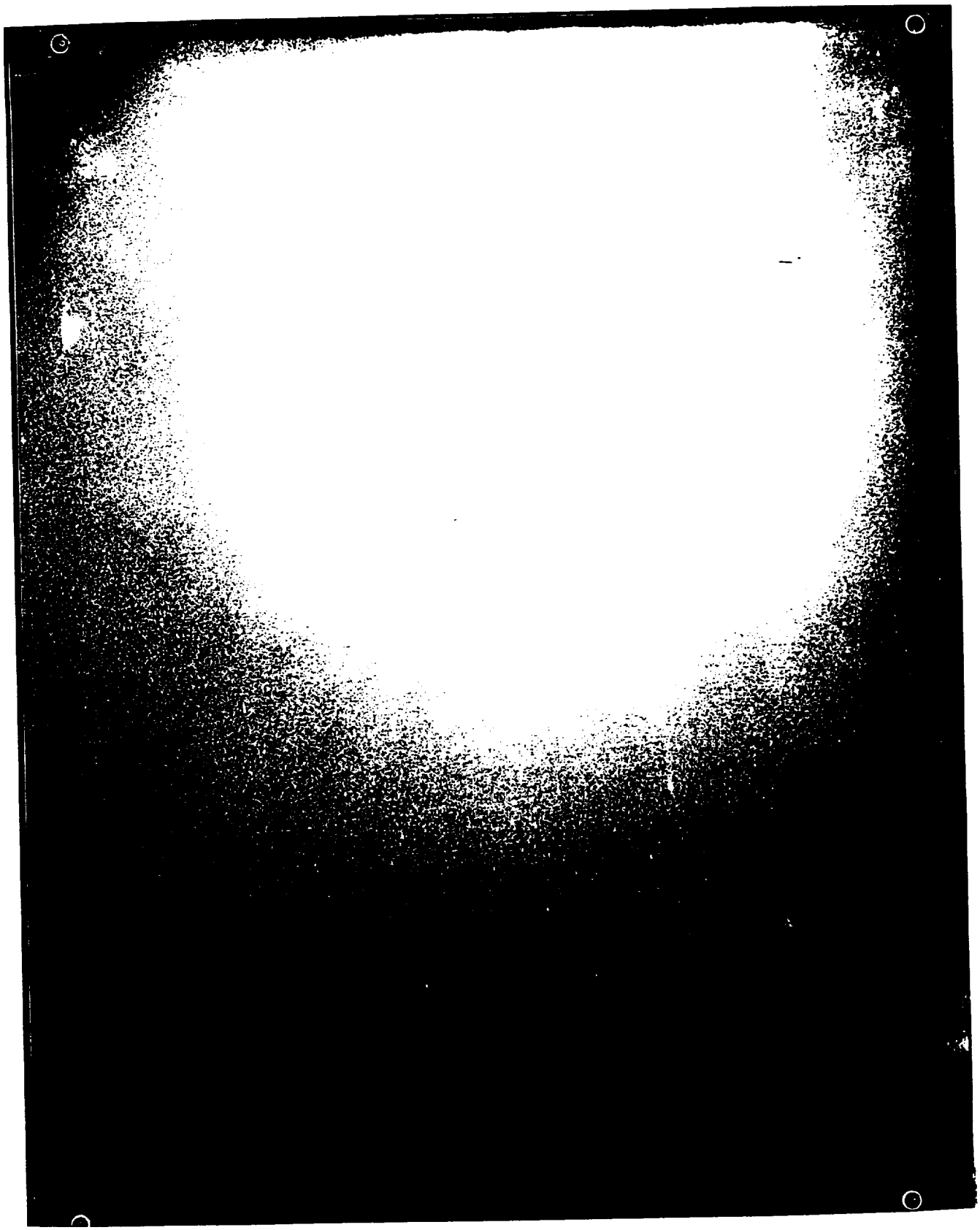

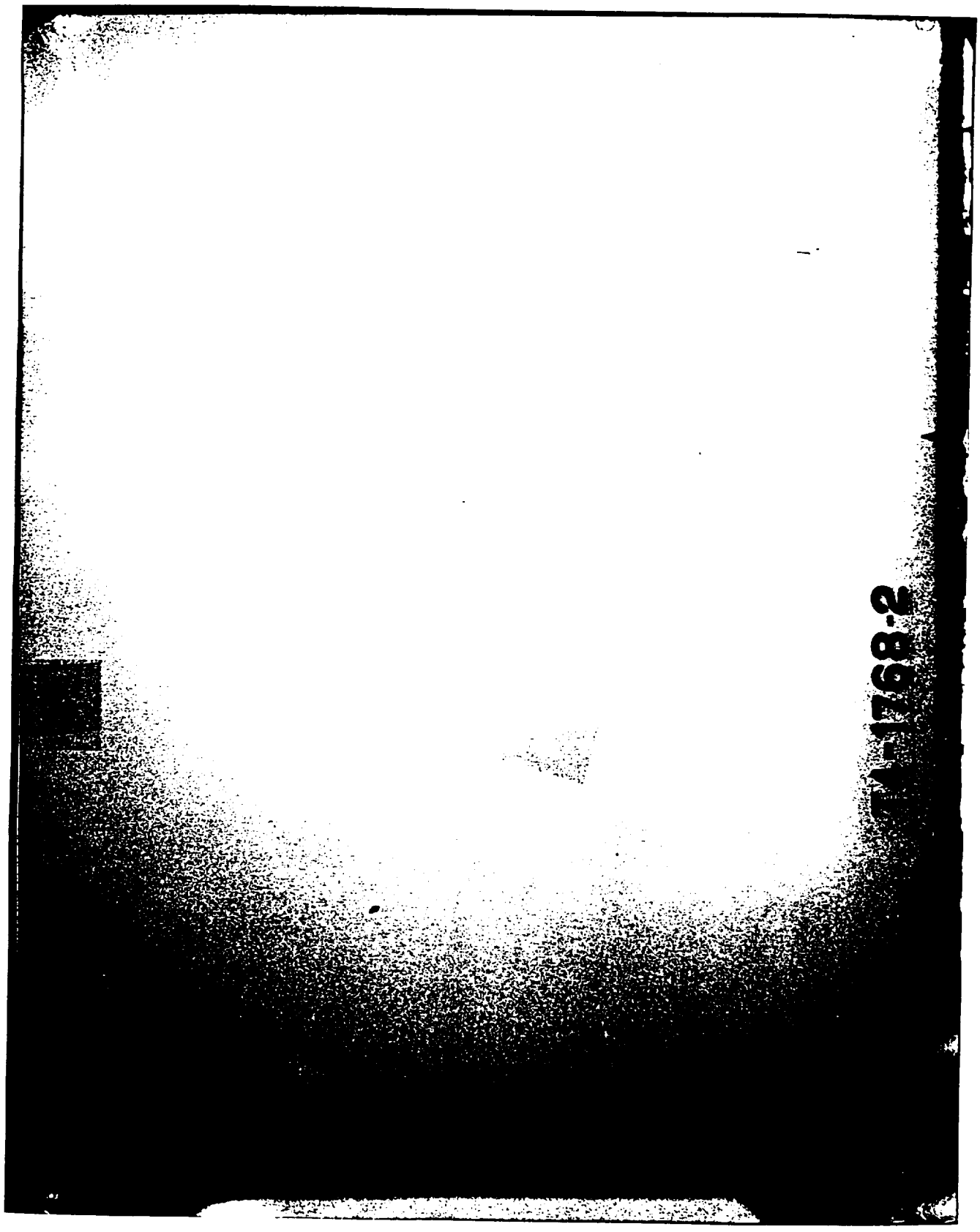
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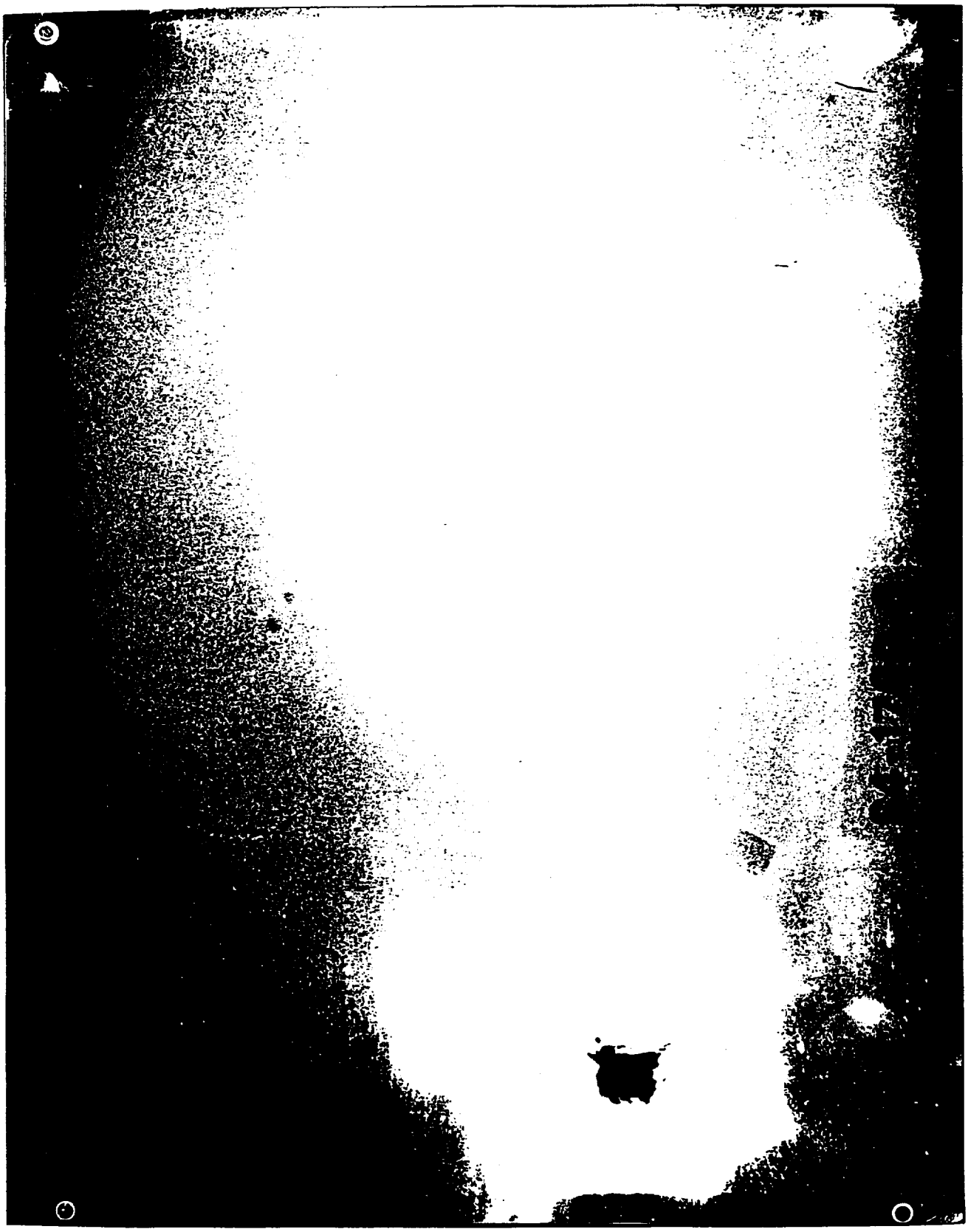

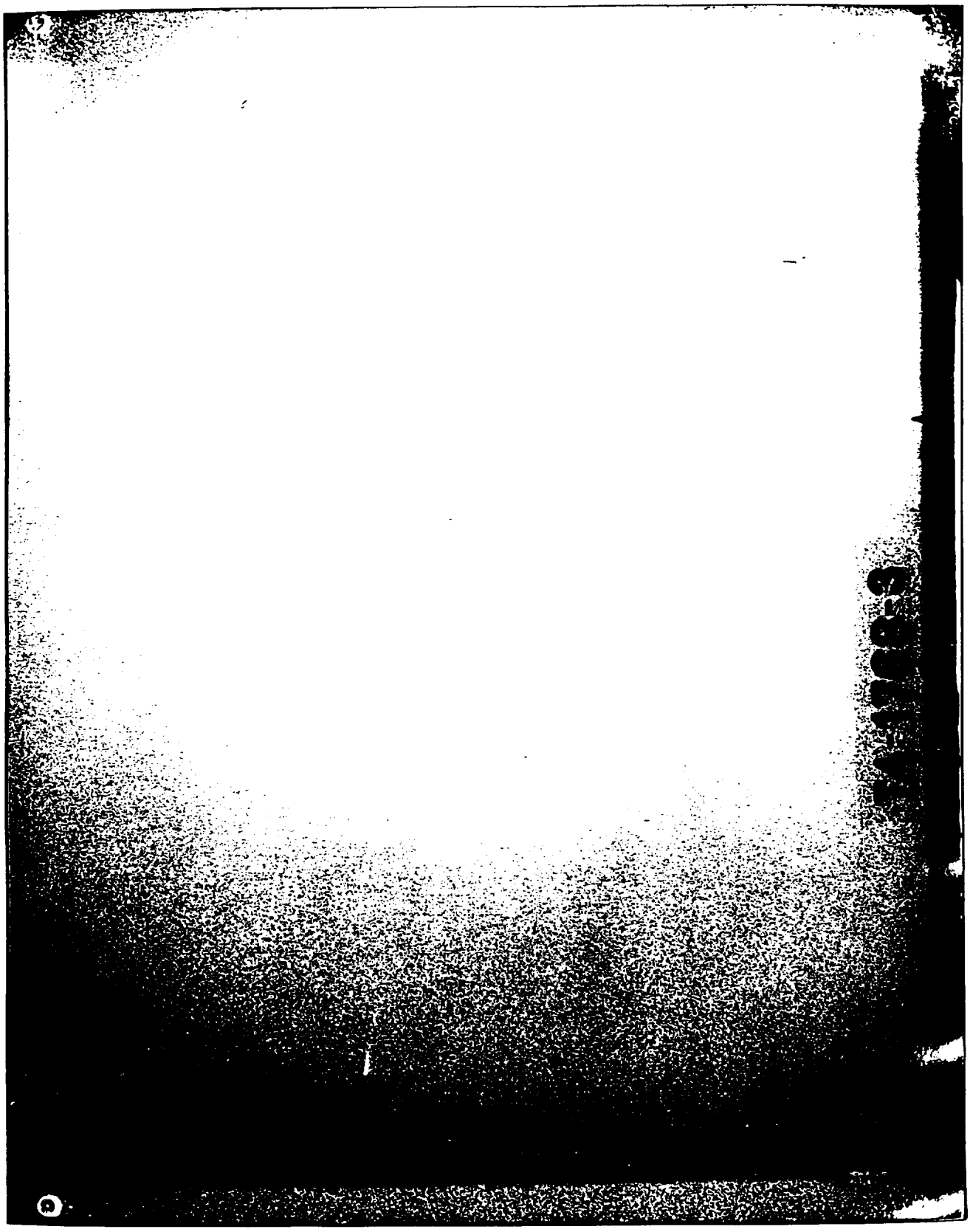

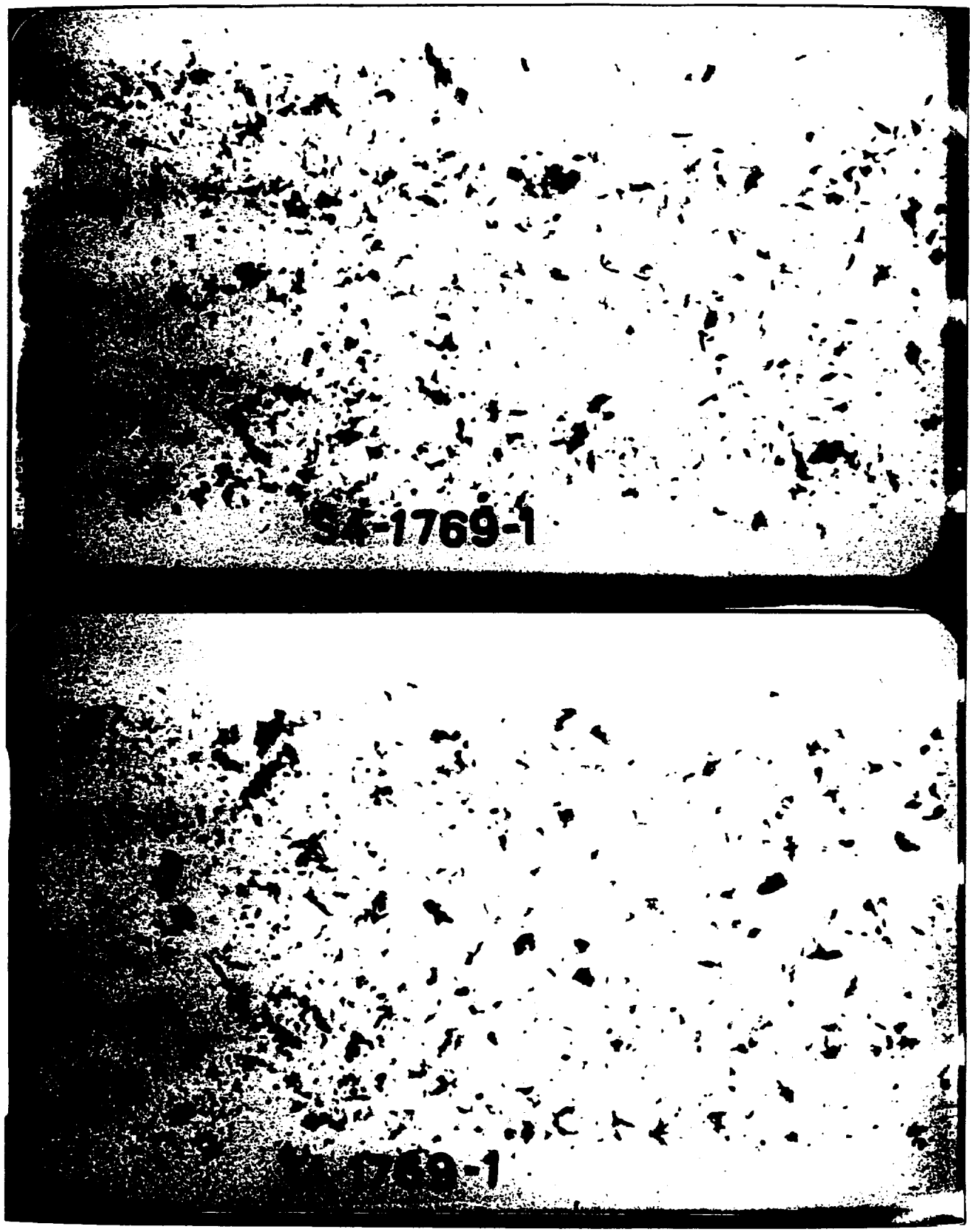
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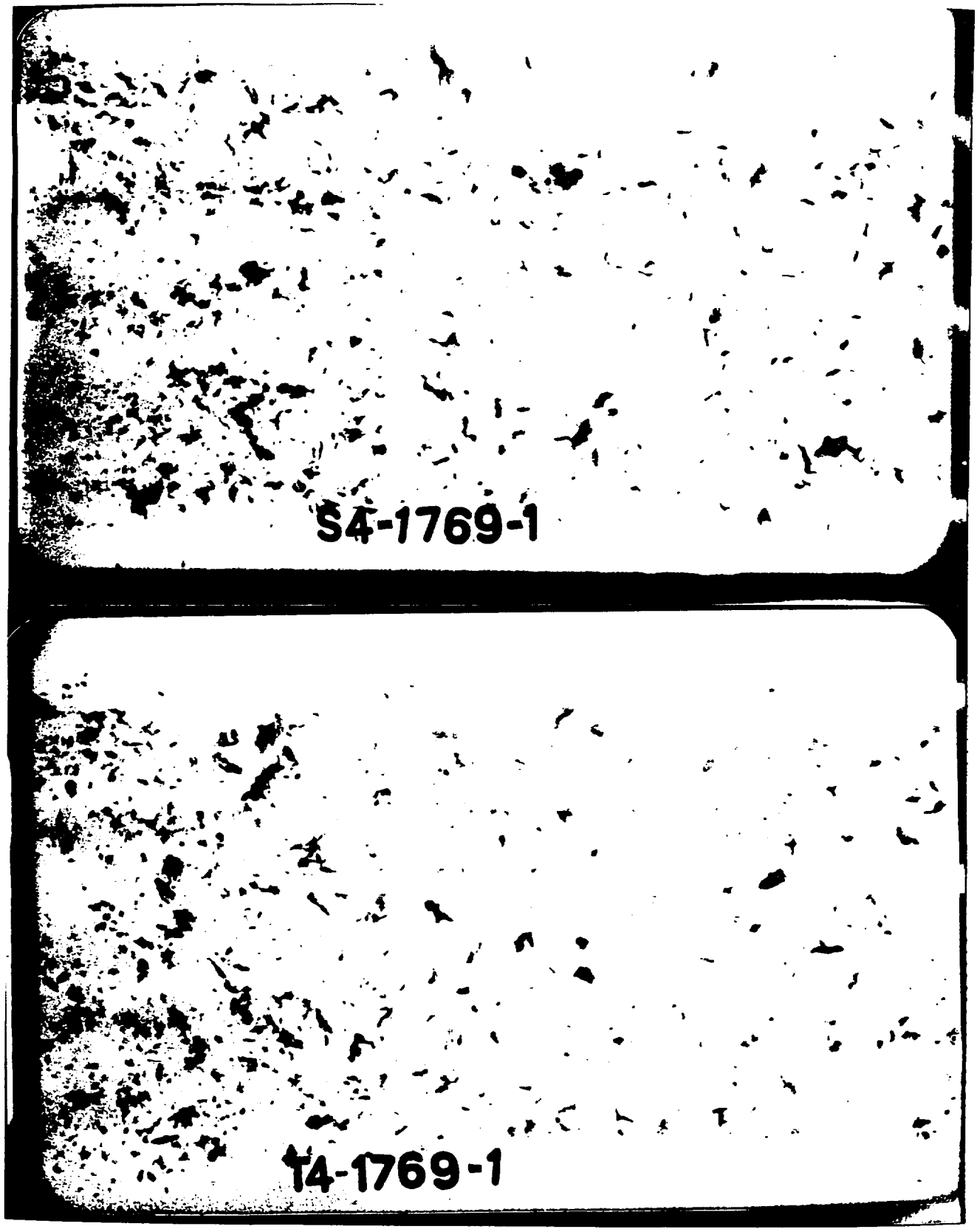
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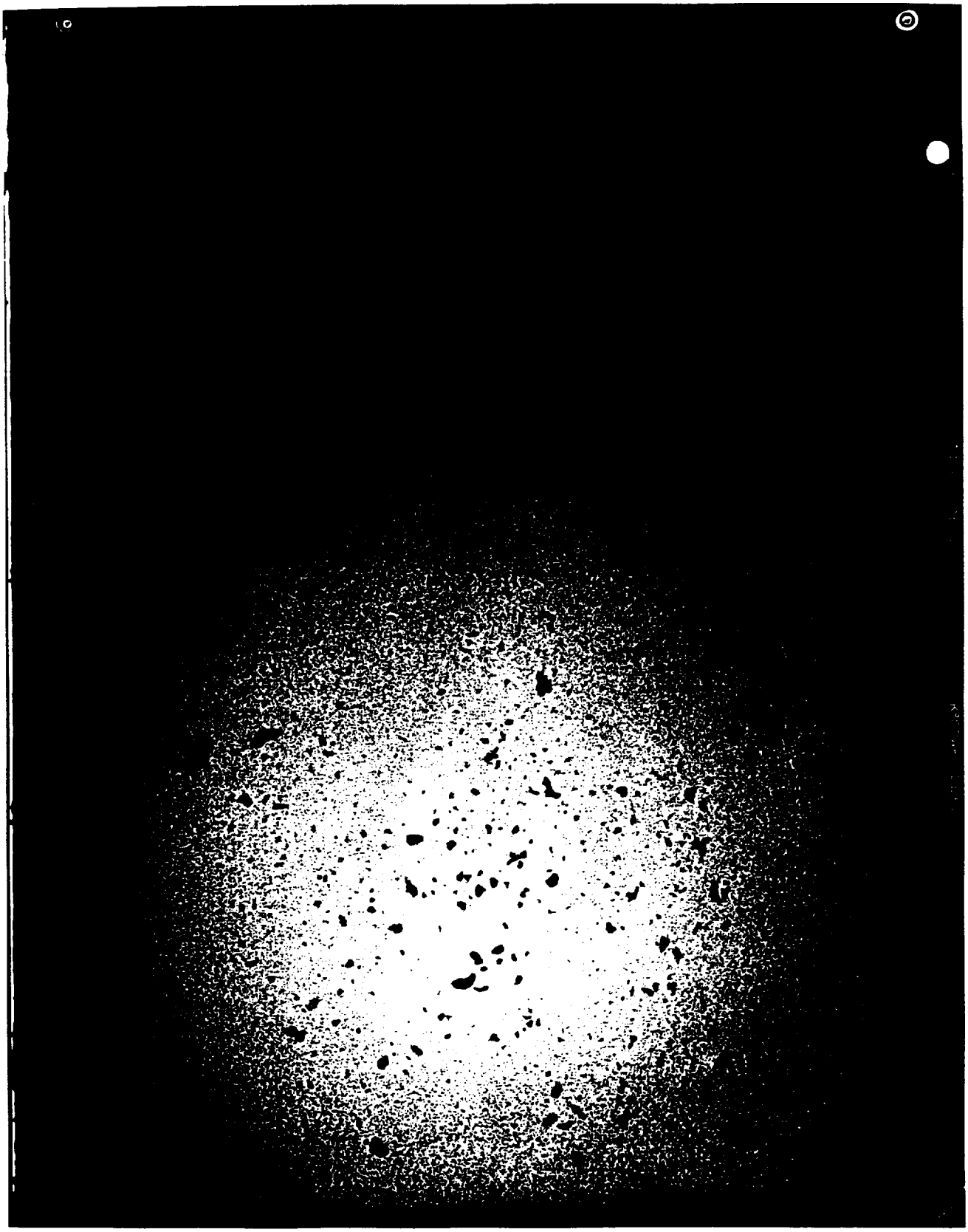

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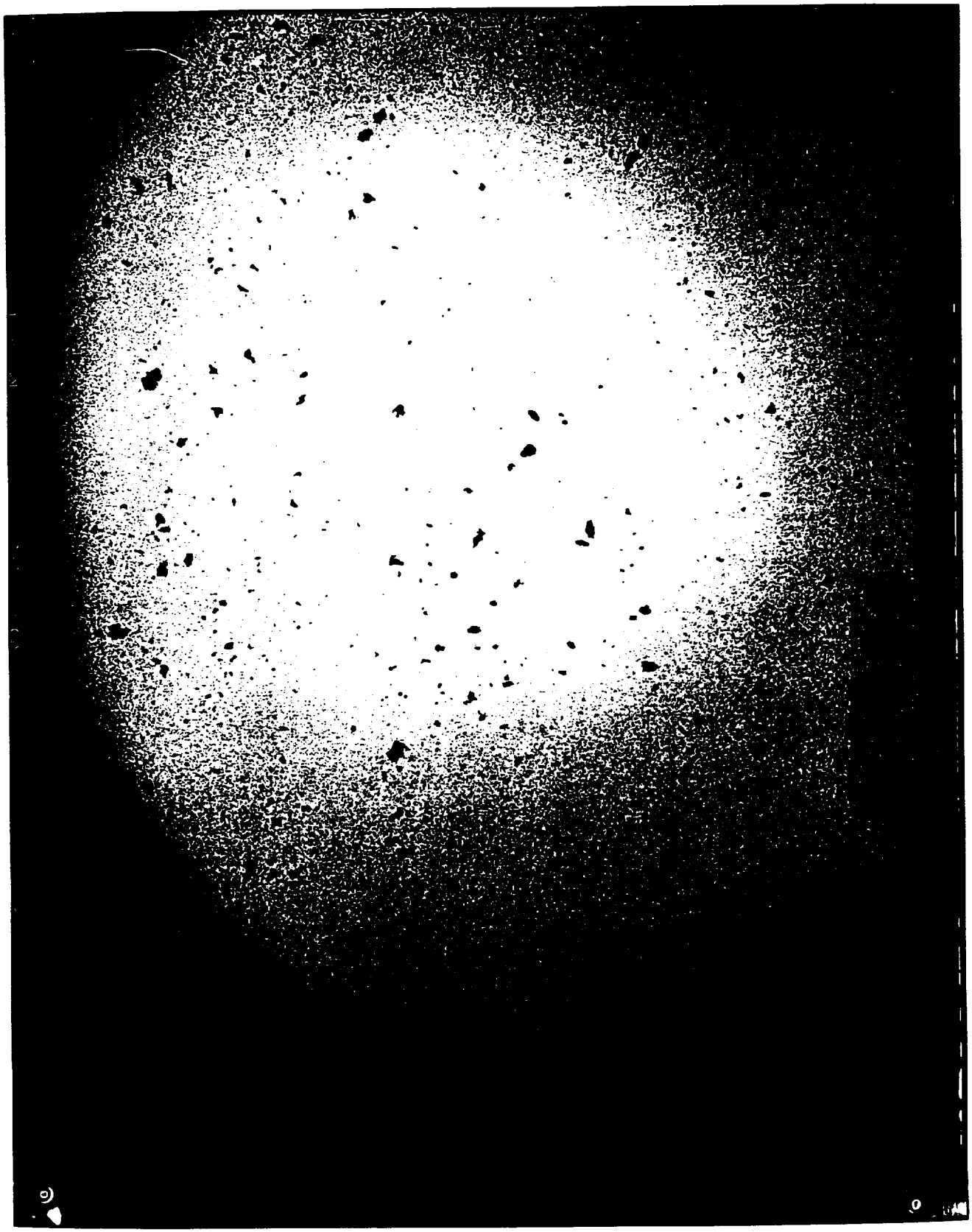

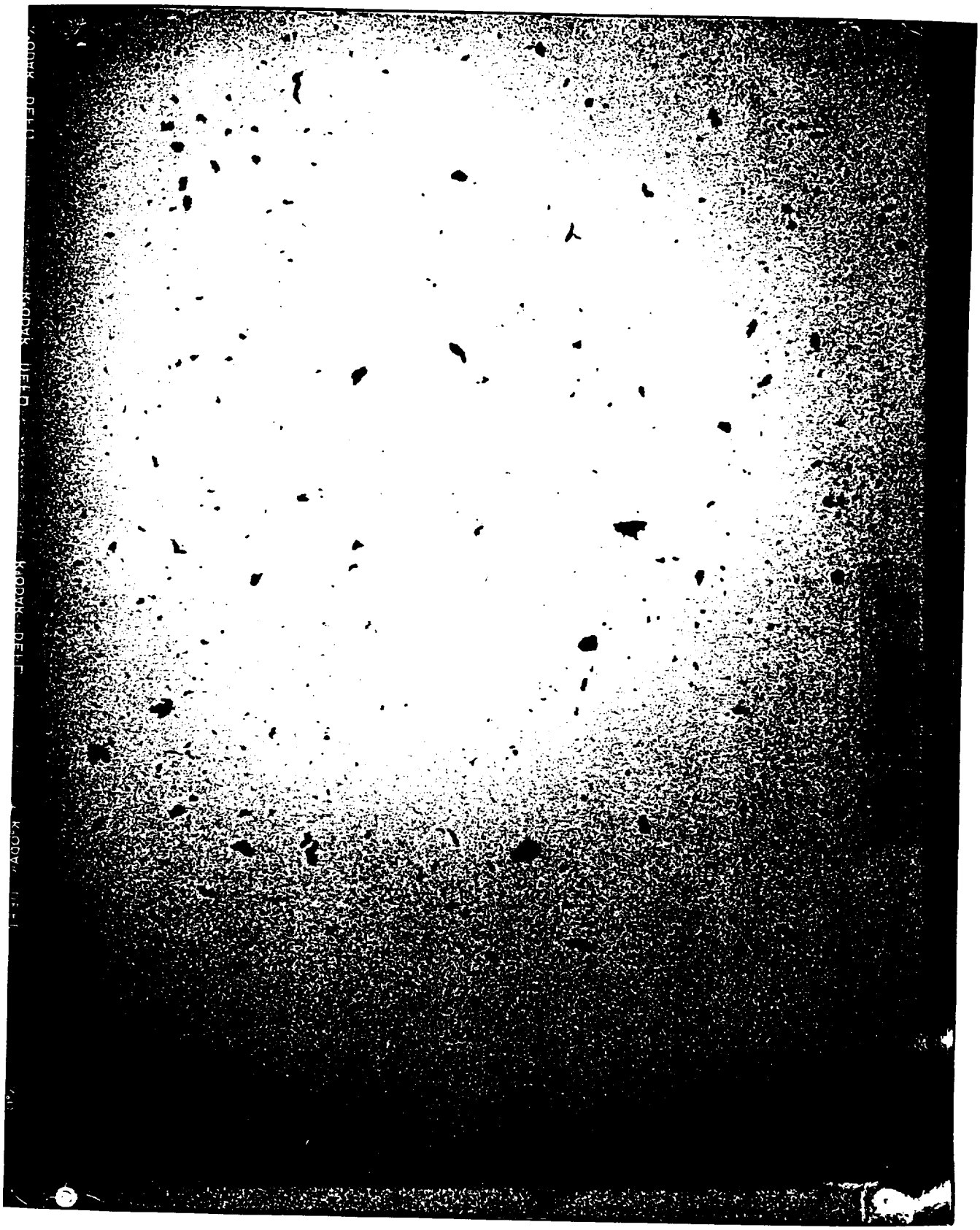

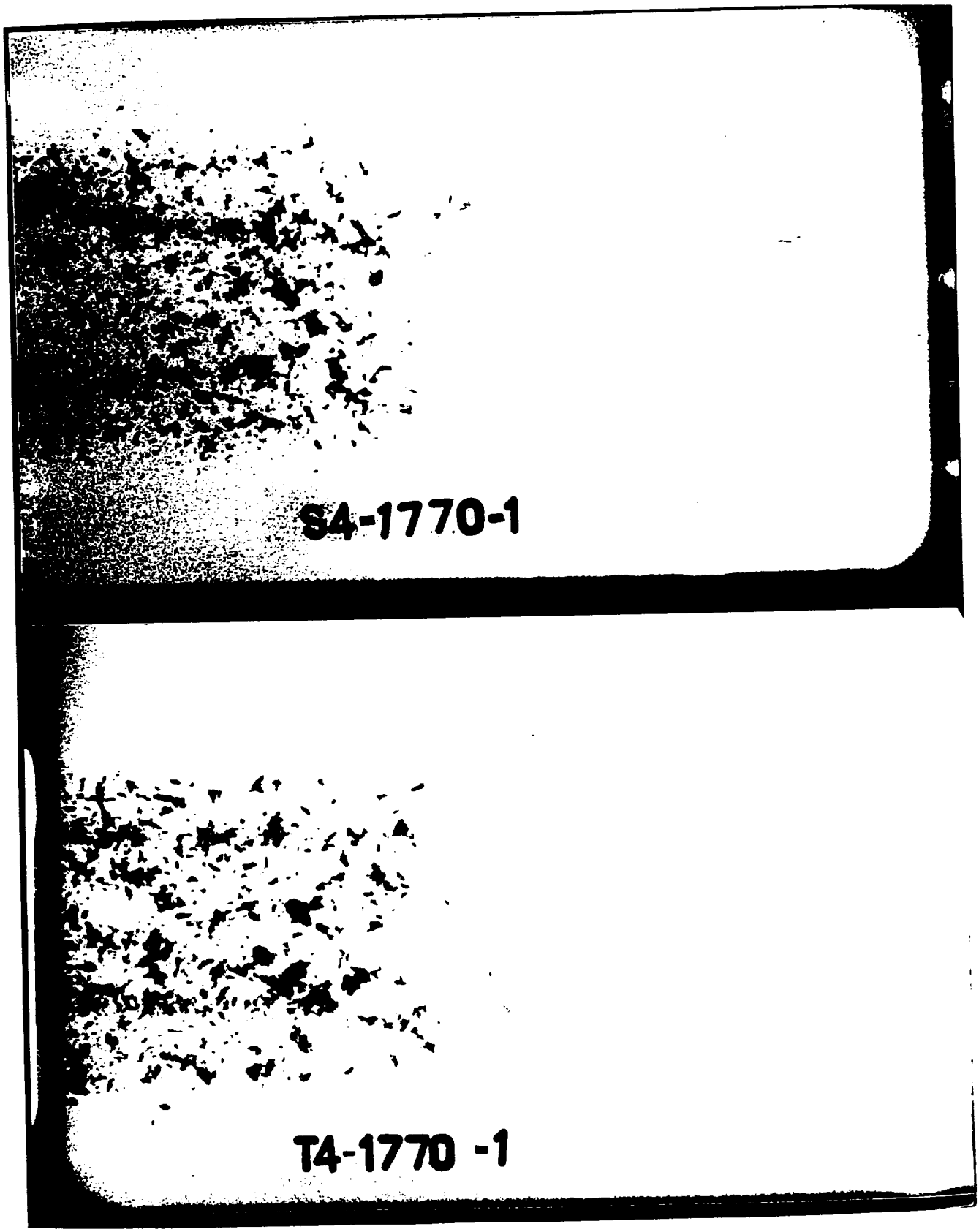
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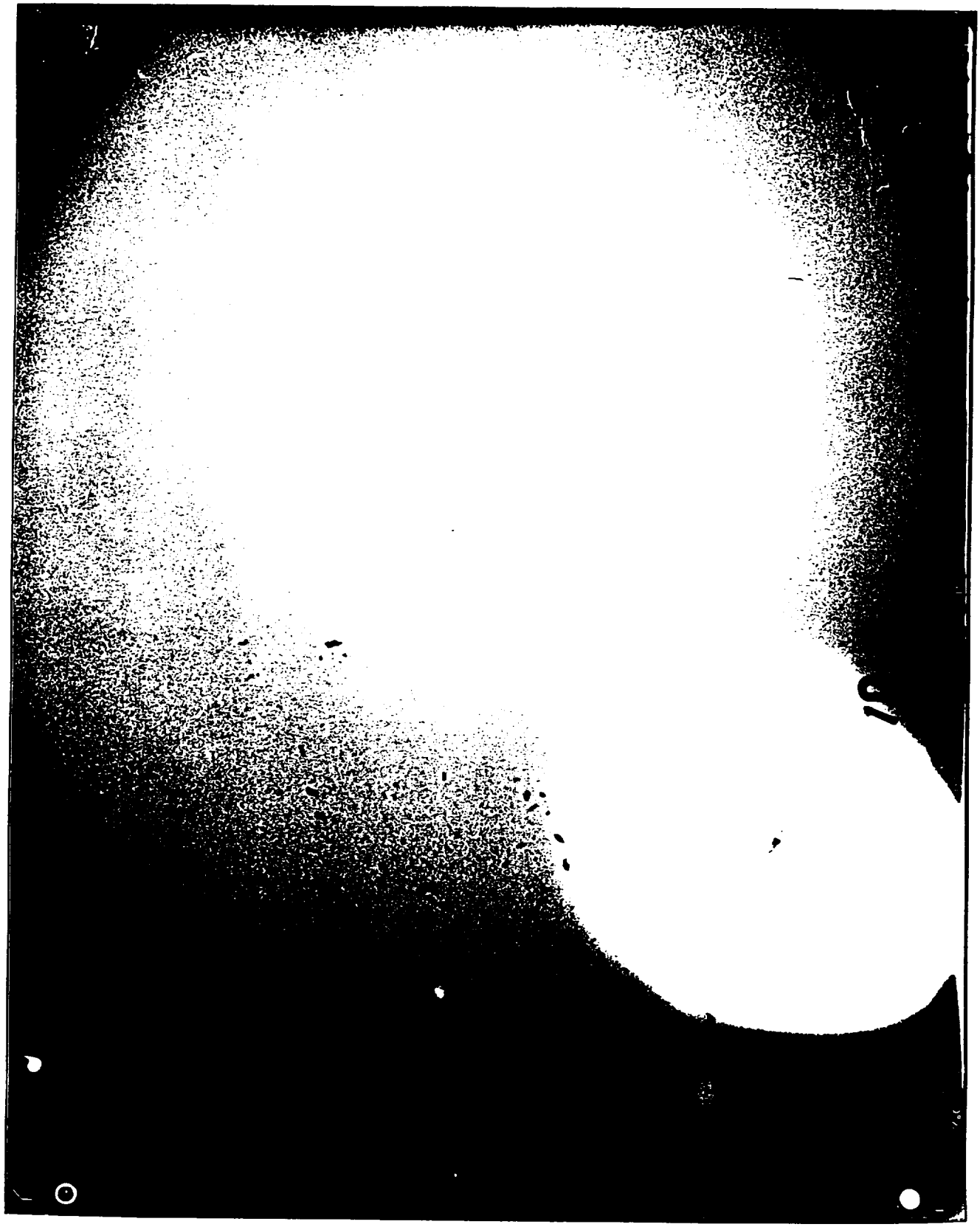

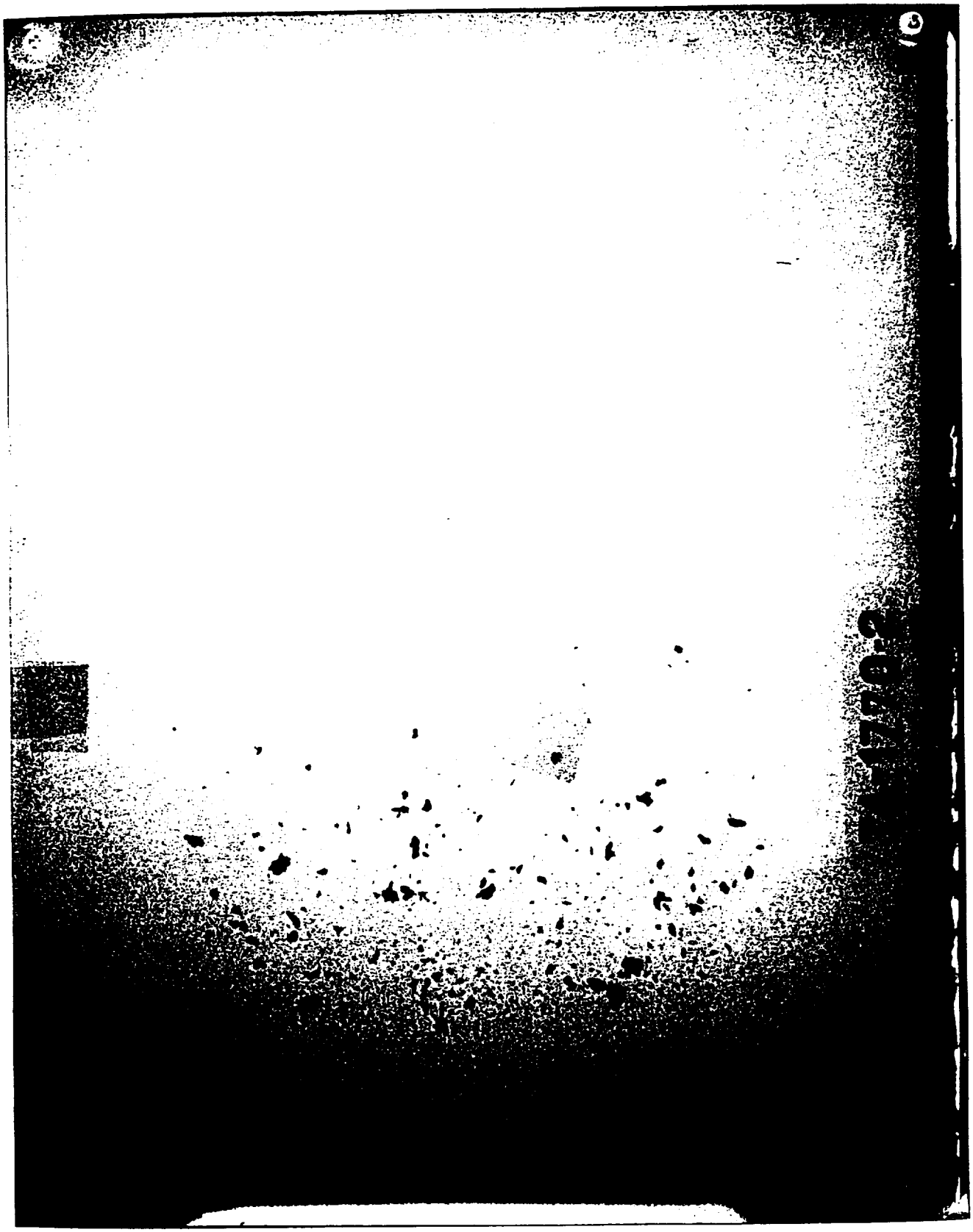

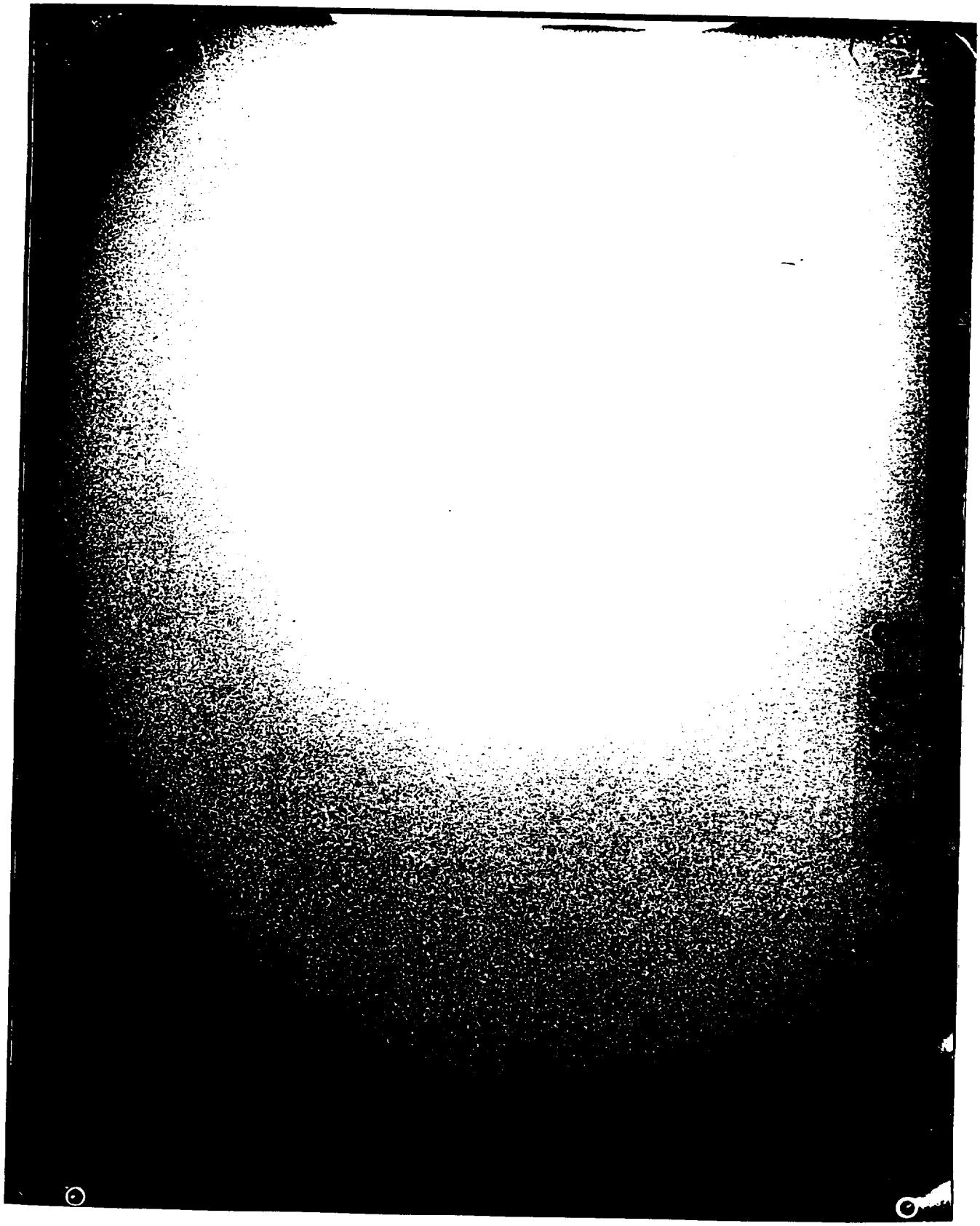

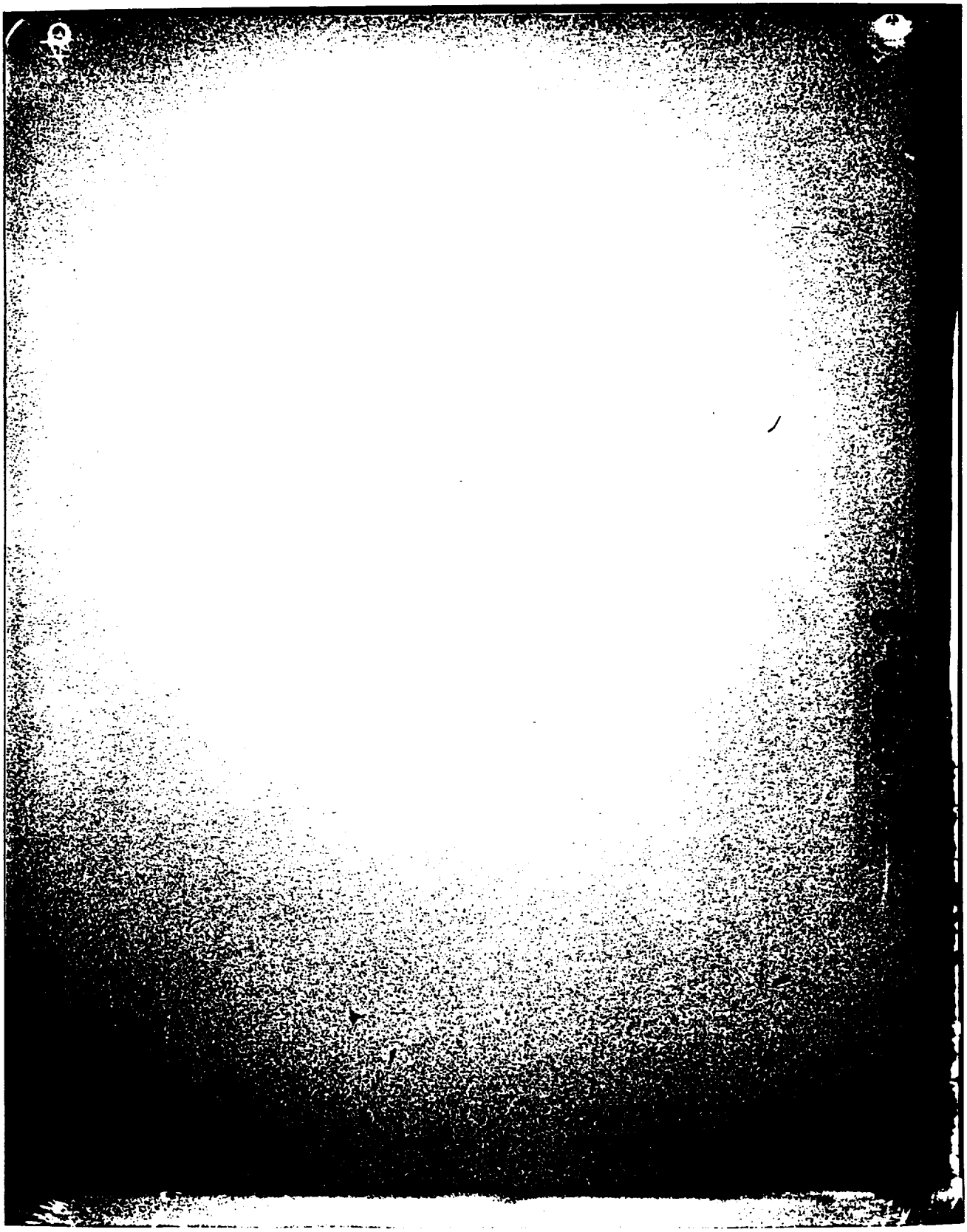

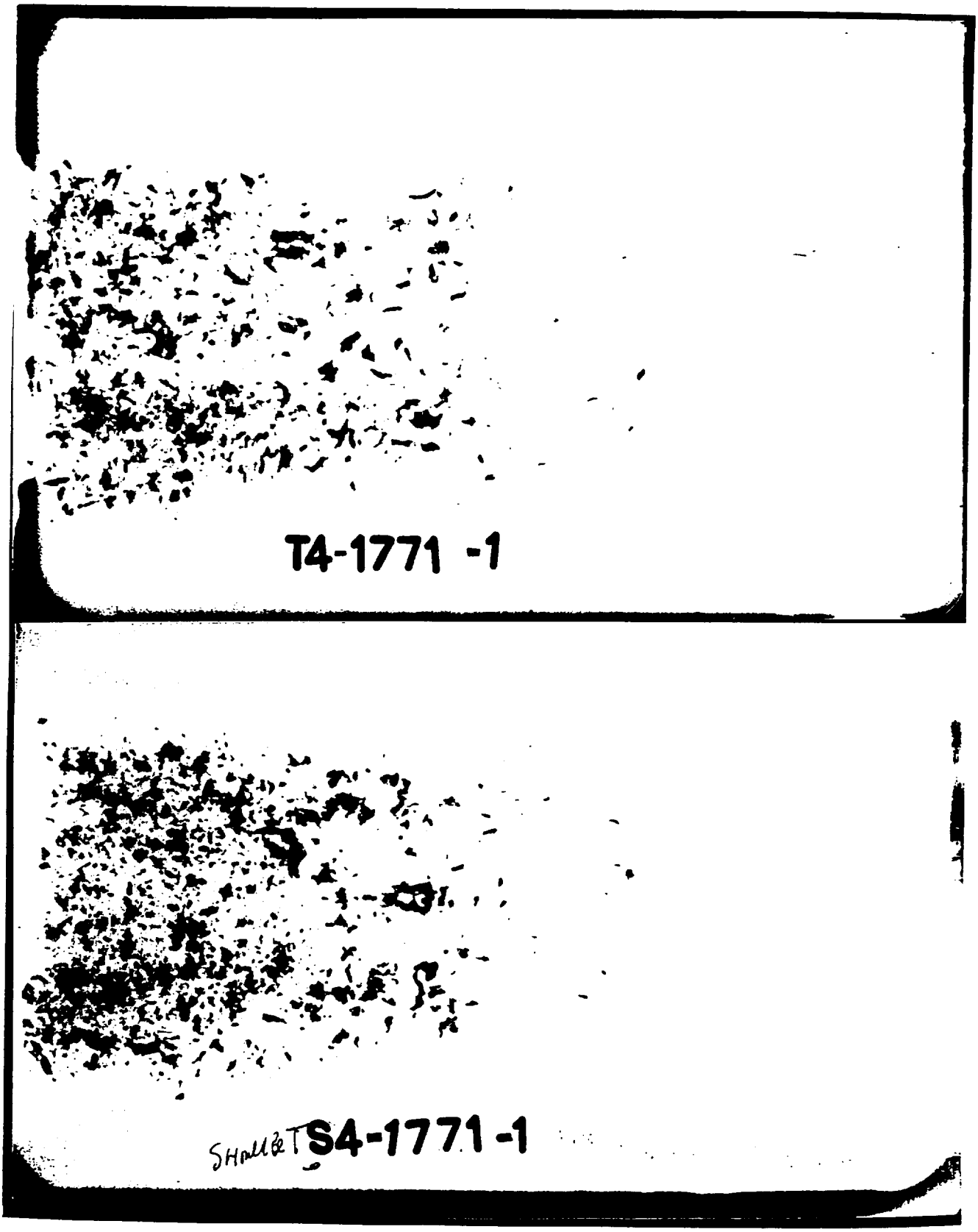
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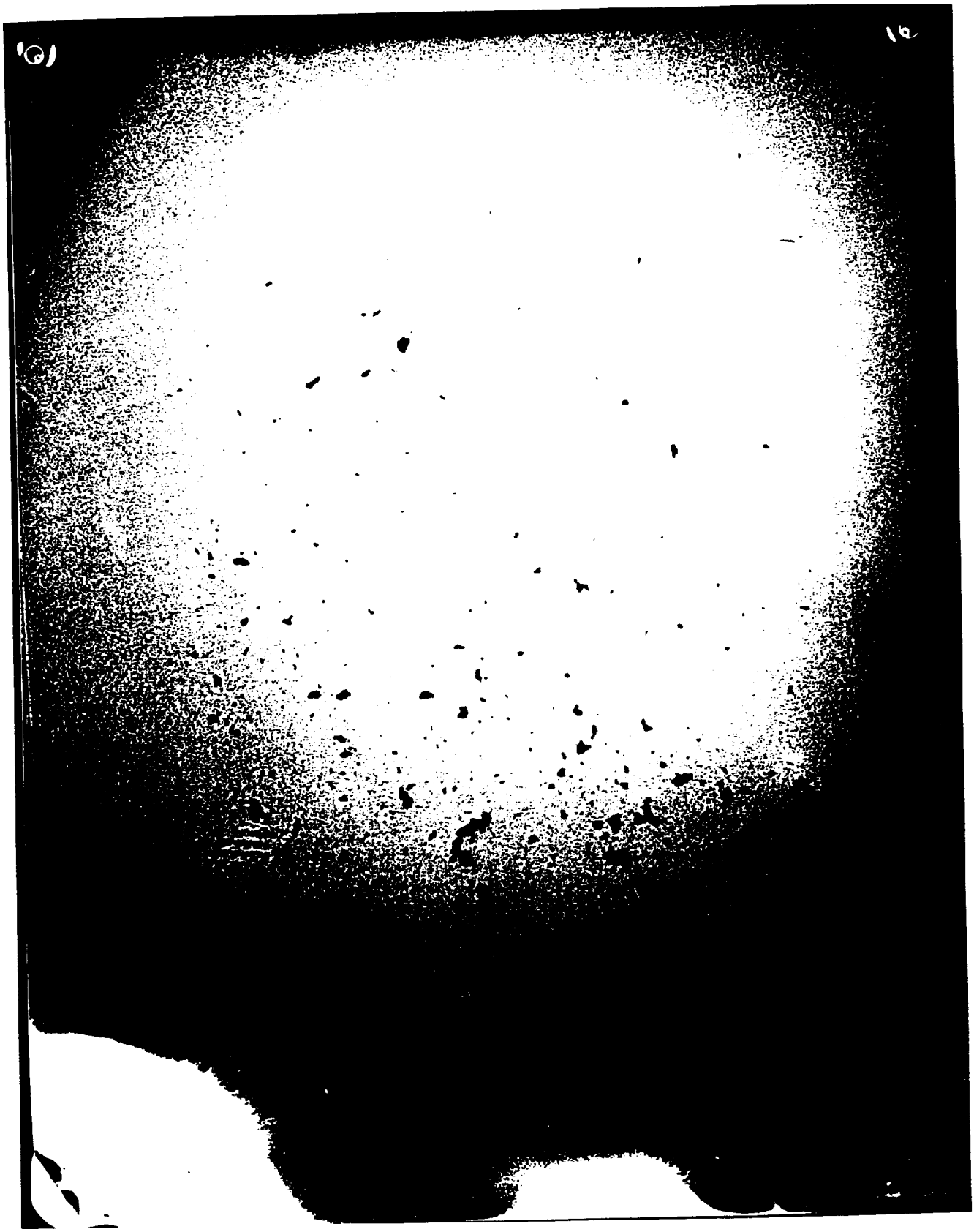

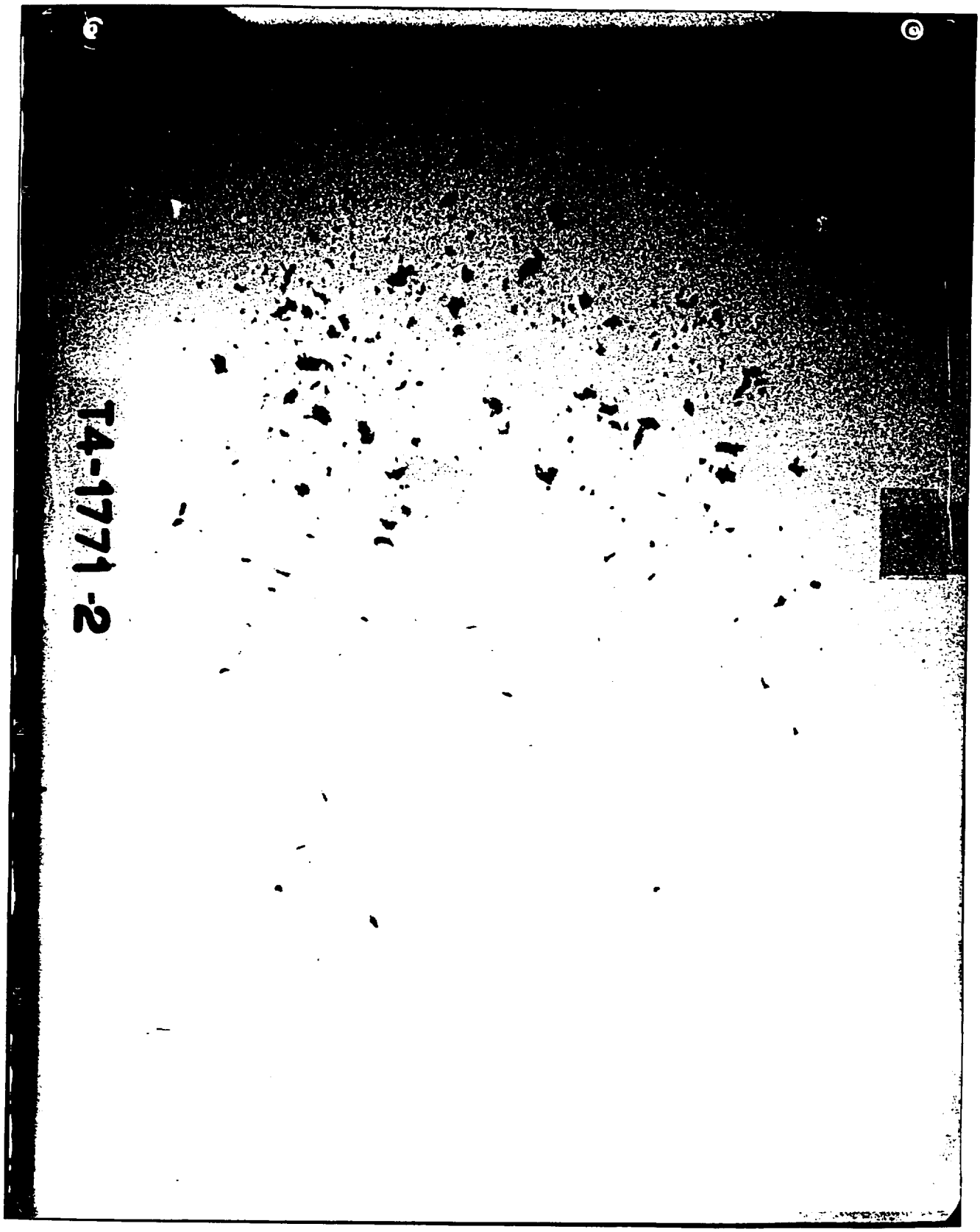
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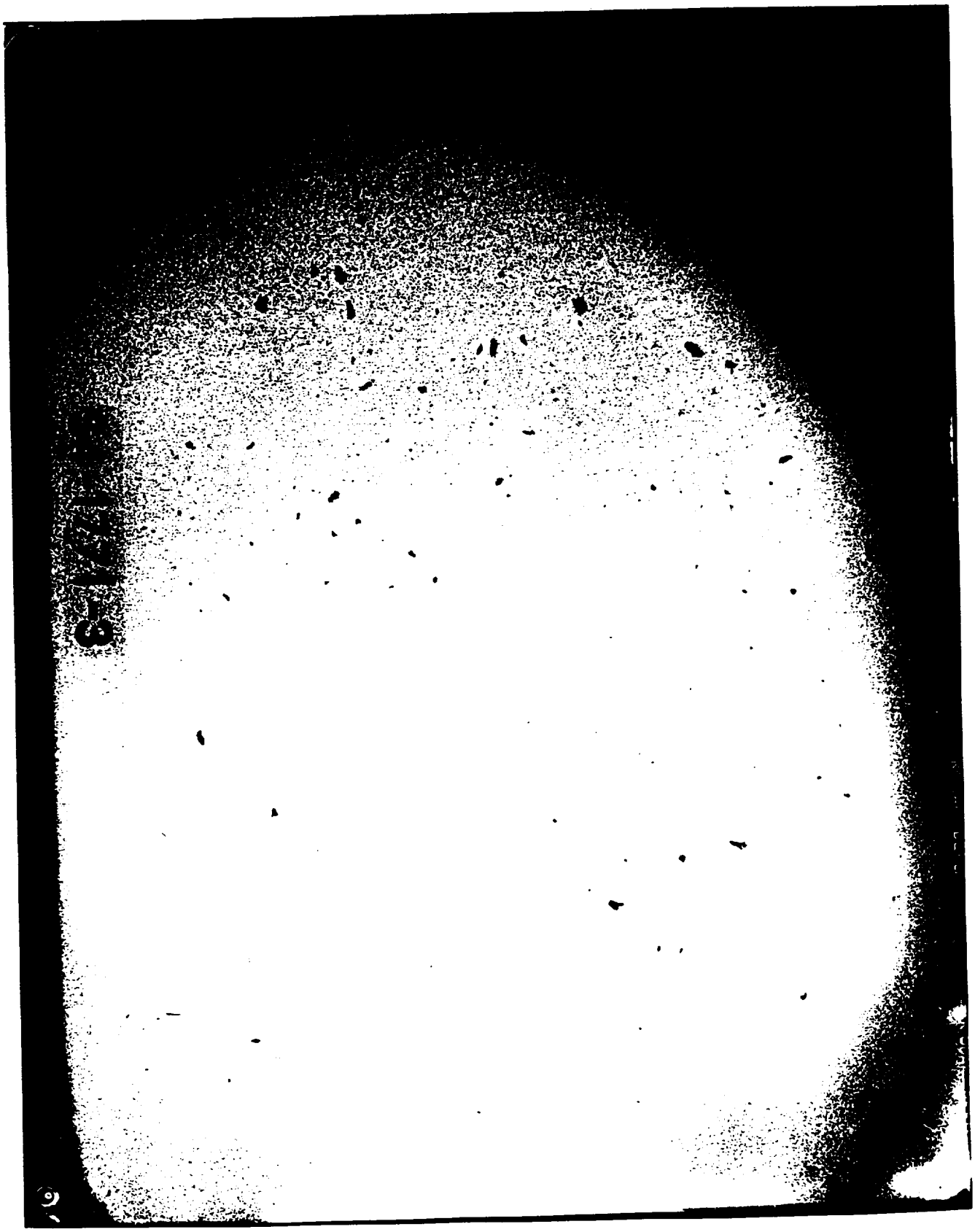
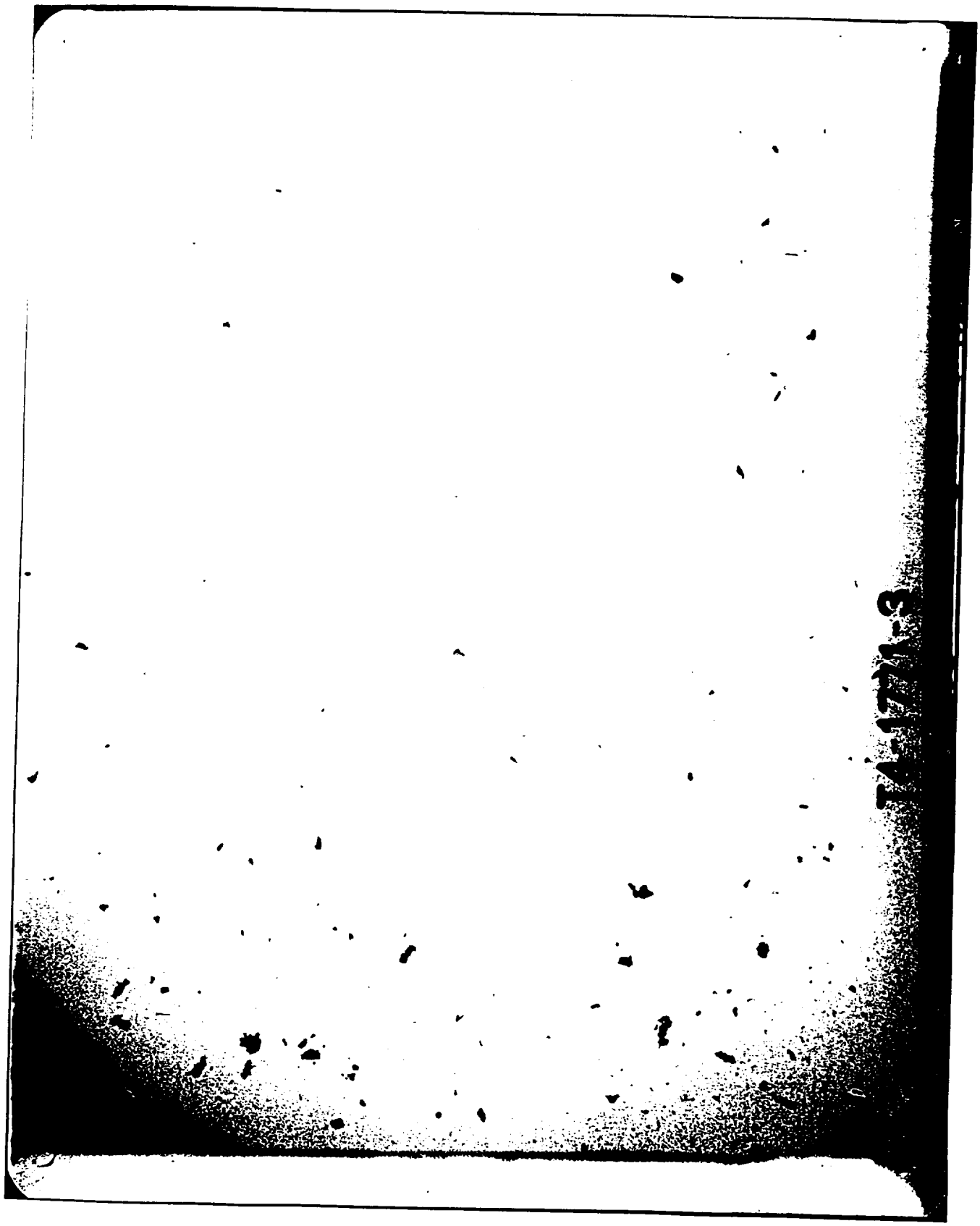
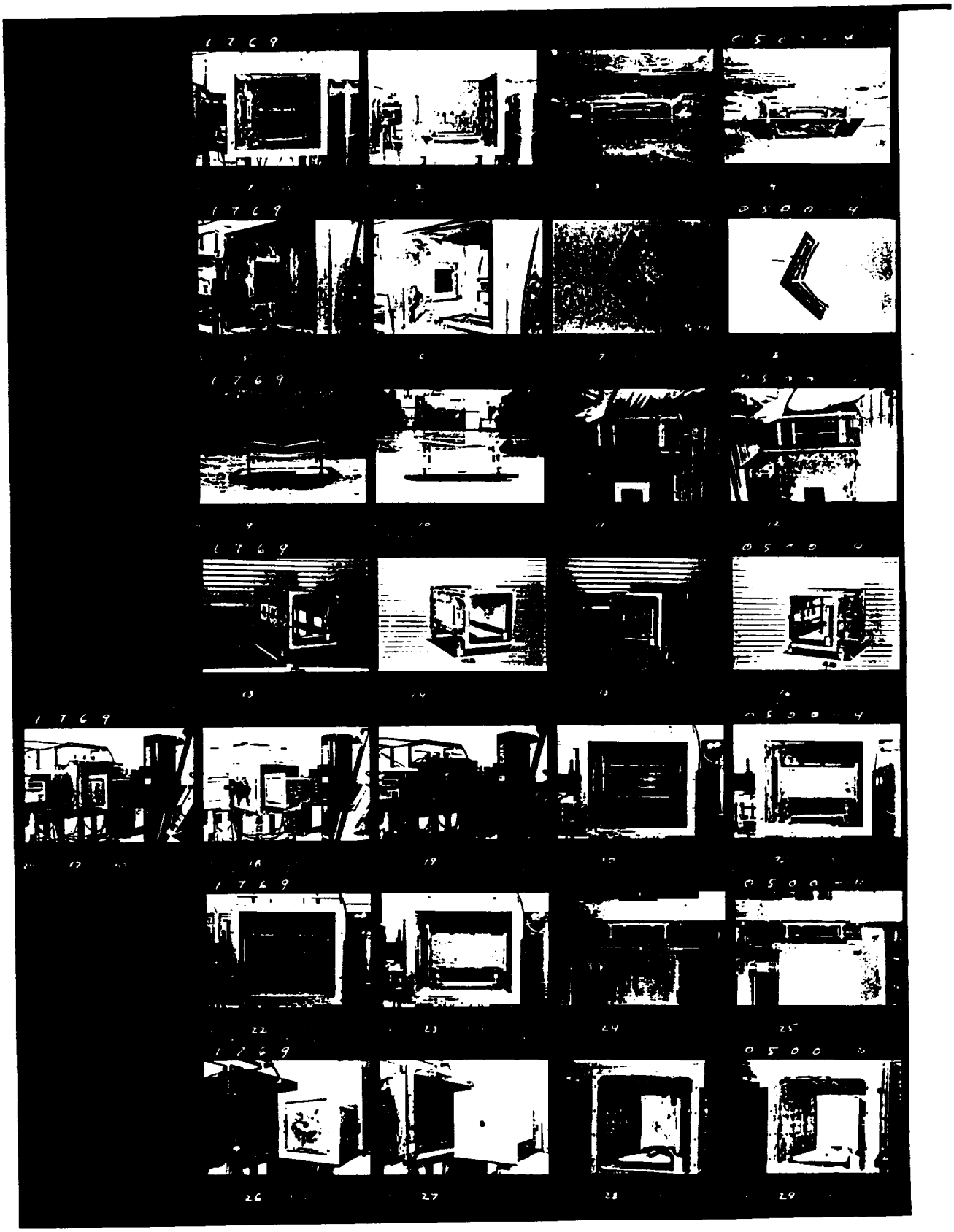
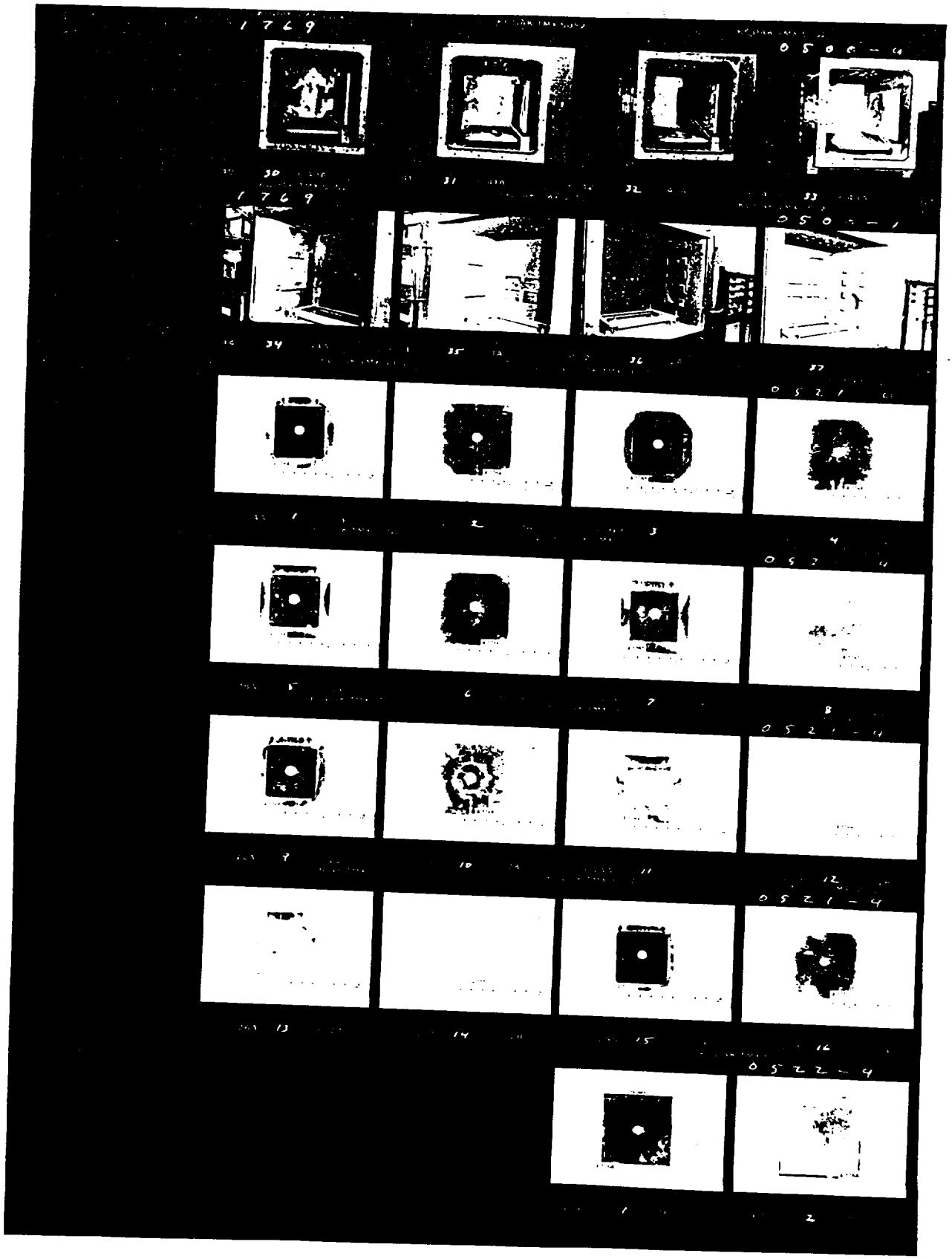
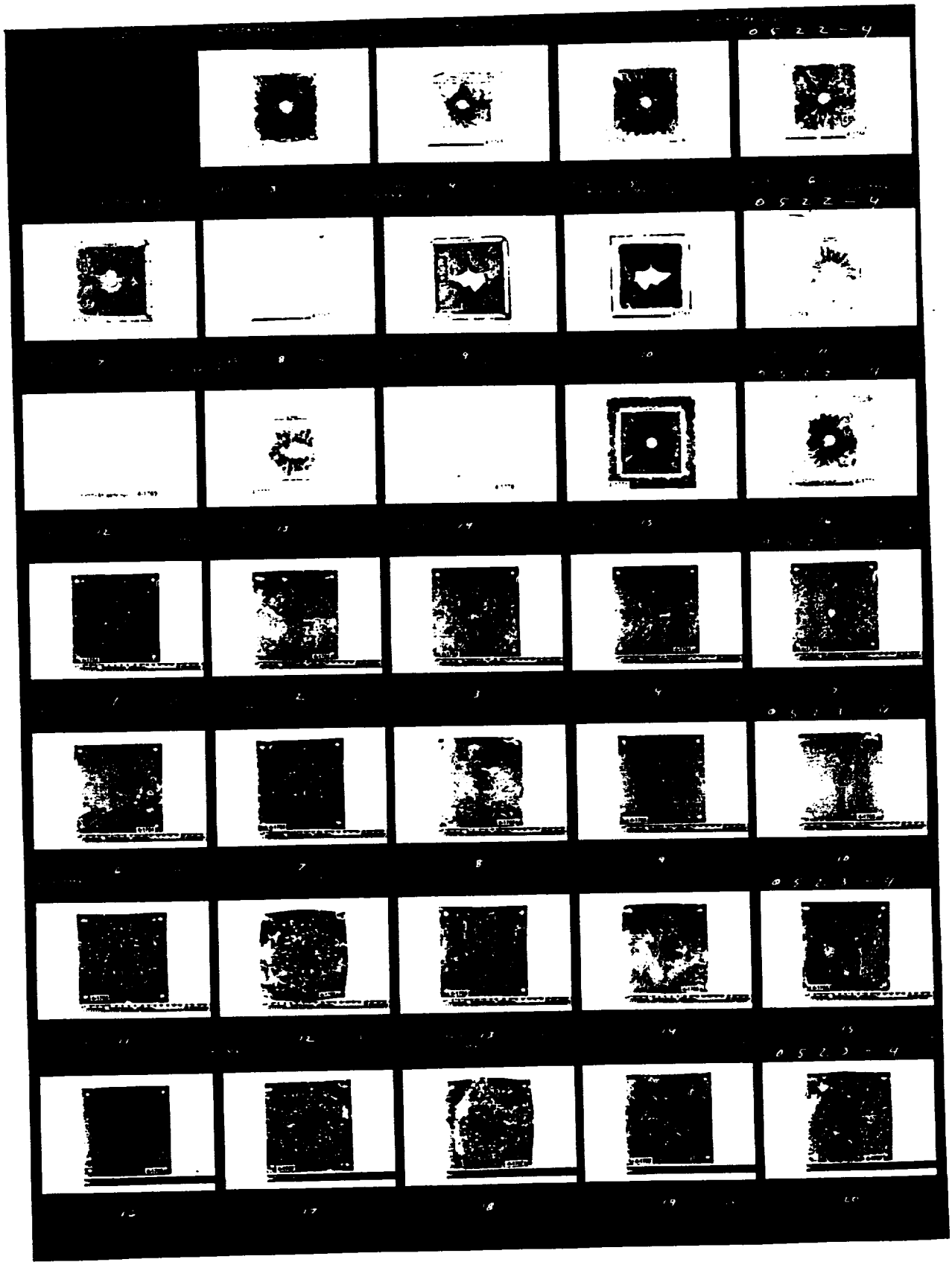
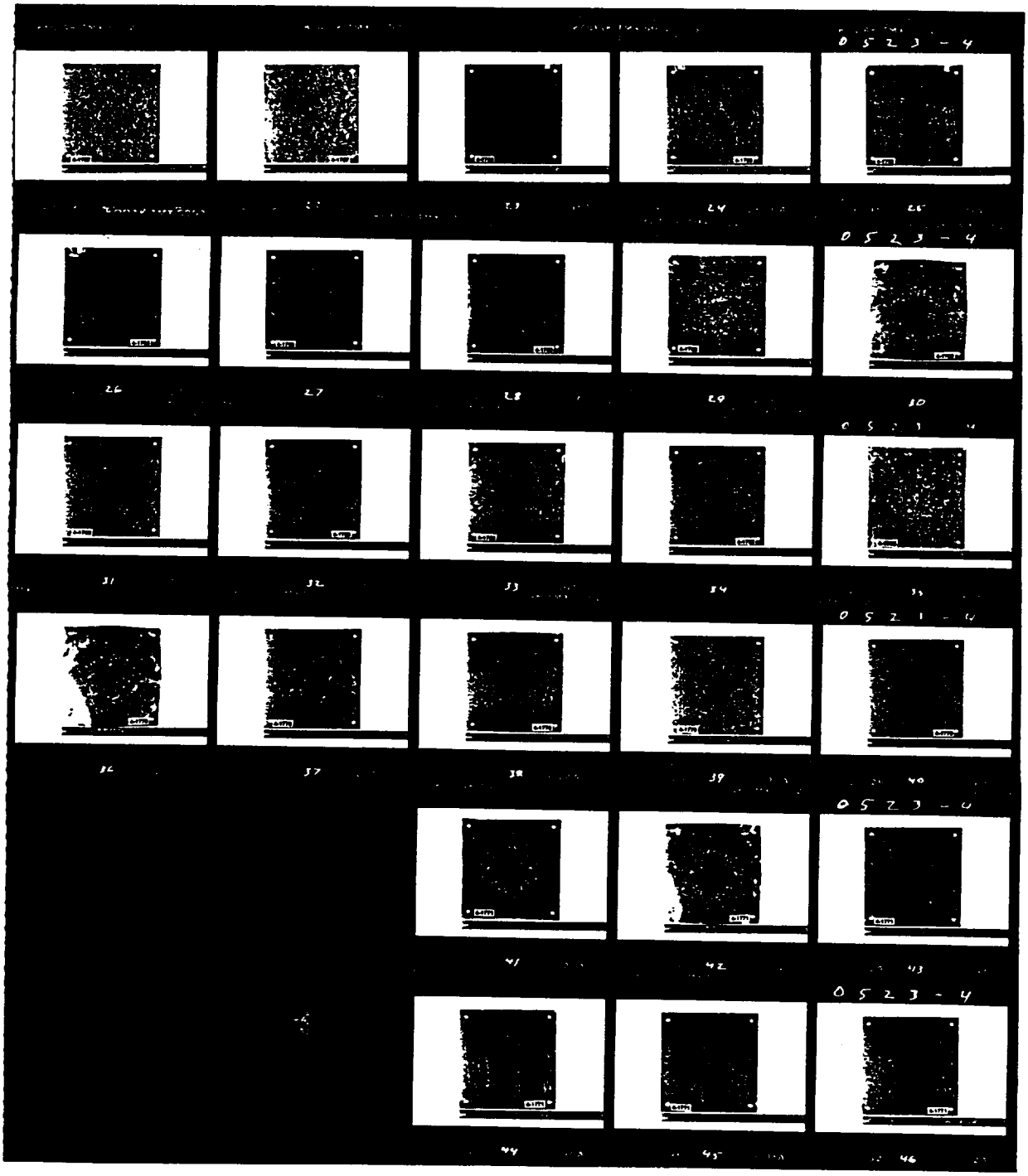


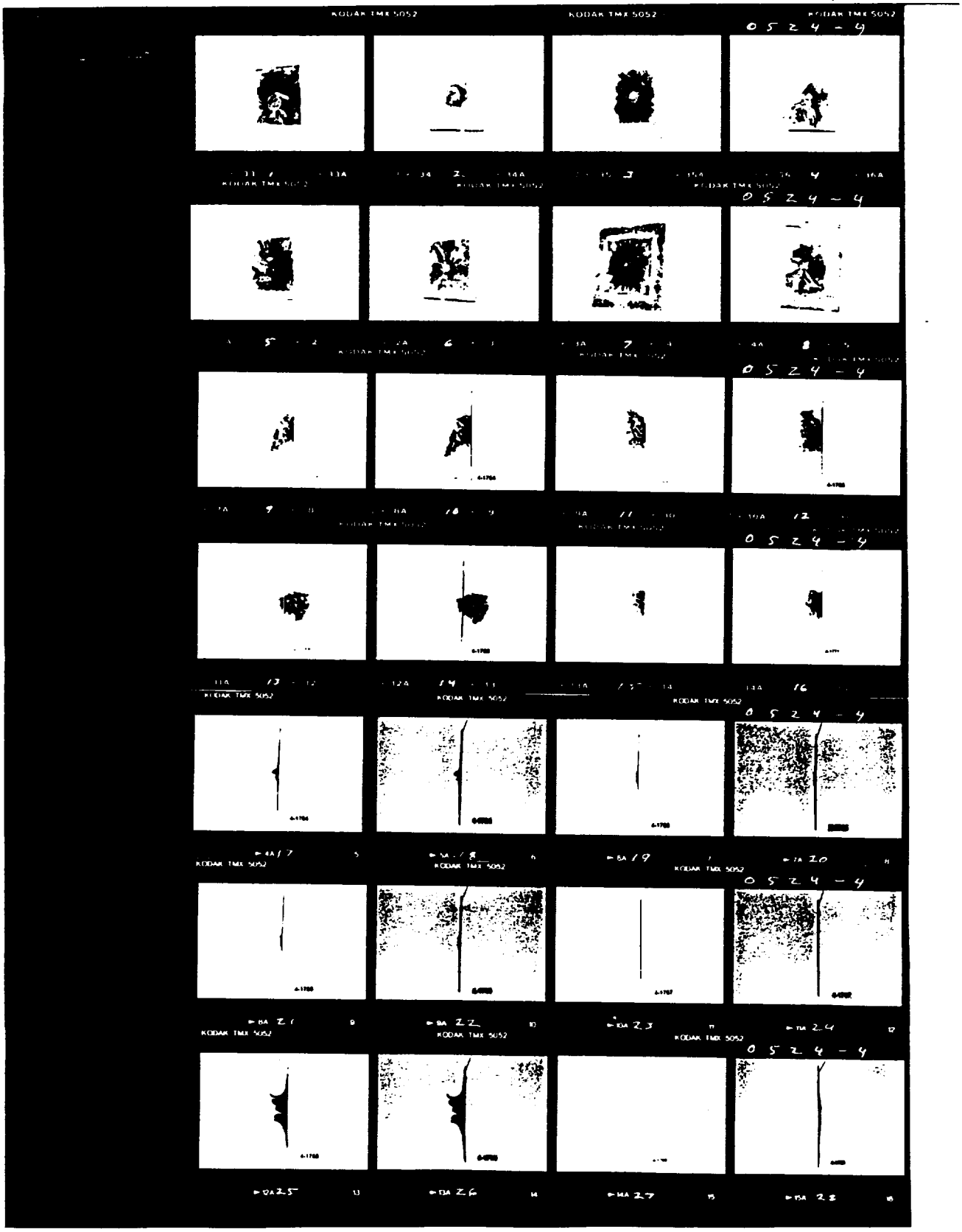


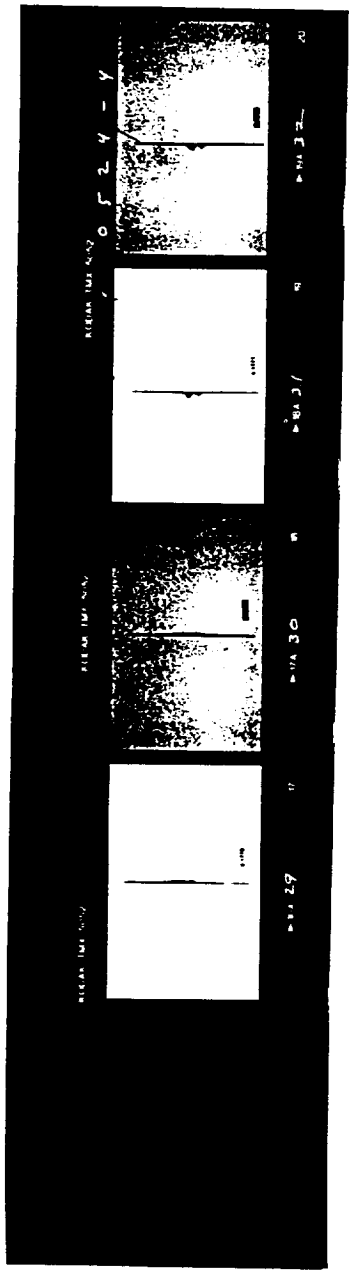









KODAK TMX 5052
0524-4



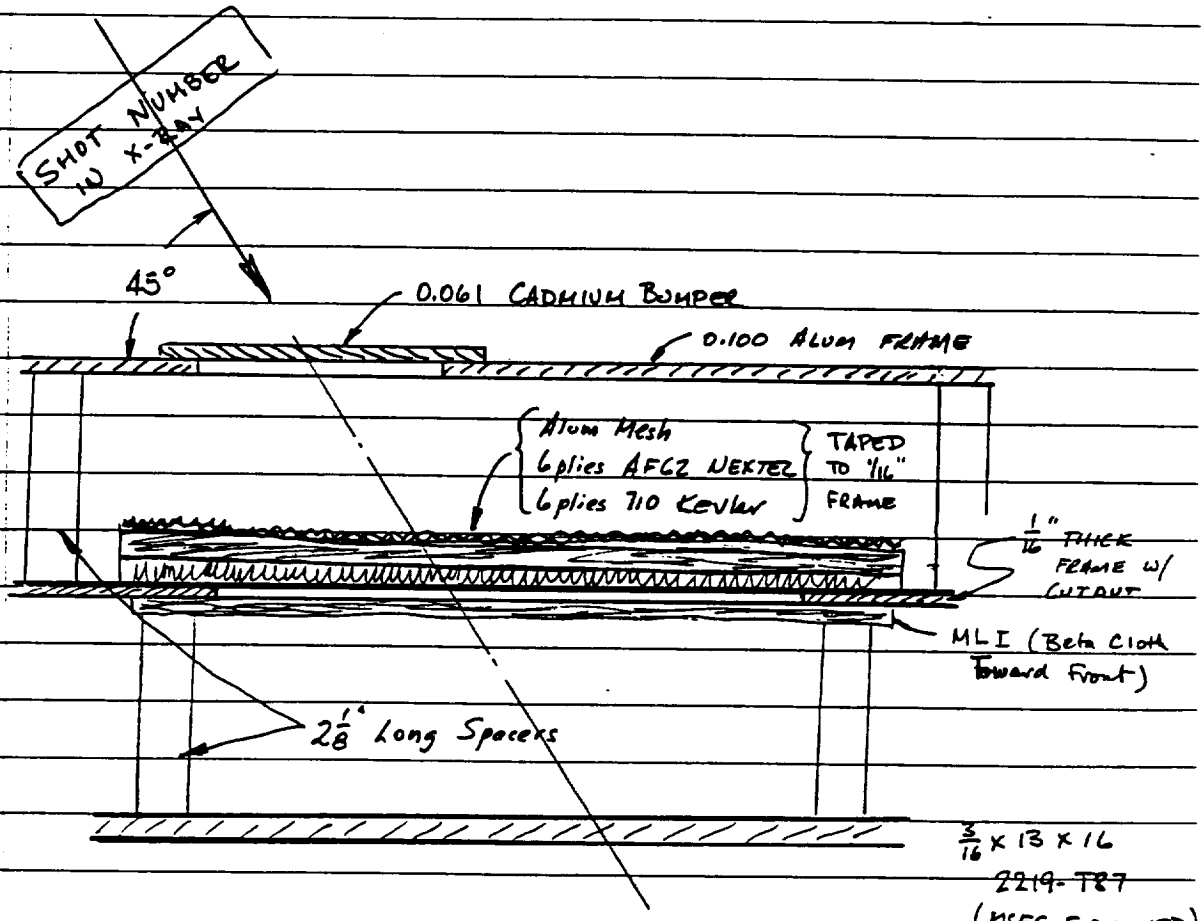
CADMIUM-ALUMINUM HYPERVELOCITY IMPACT TEST RESULTS

Shot Number	Target Type	Impact Velocity (km/s) Nominal	Scaled	Actual	Scaled	Projectile Data (ρ = 8.65 g/cm^3) Nominal Diameter (in)		Mass (g)	Equiv. Dia. (in)	
4-1723	All Aluminum	2.24	6.96	2.28	7.07	17/64	(0.2656)	1.4005	0.2662	P
4-1724	All Aluminum	2.24	6.96	2.27	7.04	1/4	(0.2500)	1.1780	0.2513	P
4-1725	Mod 2[a]	2.18	6.77	2.25	6.98	3/8	(0.3750)	3.9197	0.3752	P
4-1726	Mod 2	2.18	6.77	2.22	6.88	11/32	(0.3438)	3.0074	0.3435	P
4-1727	All Aluminum	3.55	11.00	3.51	10.88	5/16	(0.3125)	2.3188	0.3150	P
4-1728	All Aluminum	3.55	11.00	3.59	11.13	9/32	(0.2812)	1.6460	0.2792	NP
4-1729	All Aluminum	2.24	6.96	2.23	6.91	15/64	(0.2344)	0.9420	0.2333	P
4-1730	Mod 2	2.18	6.77	2.19	6.79	5/16	(0.3125)	2.2174	0.3103	P
4-1731	All Aluminum (Cad)	2.24	6.96	2.22	6.88	9/32	(0.2812)	1.6469	0.2810	NP
4-1732	All Aluminum (Cad)	2.24	6.96	2.23	6.91	5/16	(0.3125)	2.2944	0.3138	P

a MLI / Nextel / Kevlar / Gr-Ep package 0.258 in. too close to bumper.

TARGET LAY-UP 4-1576 & 4-1577

(per our notes & Telecon b Angie Nolan 20 Jan 93)



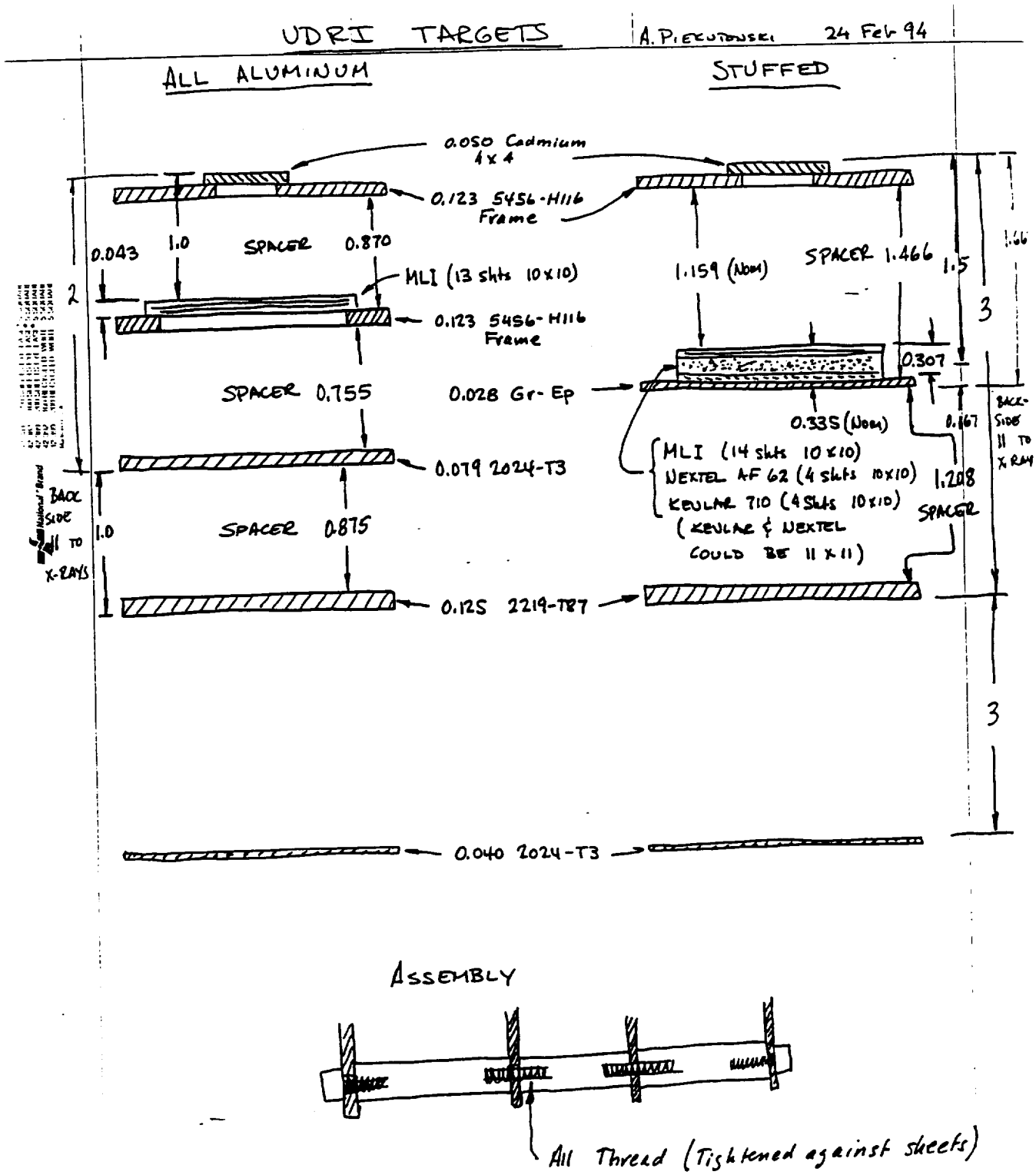
NOTE REGARDING PHOTOGRAPHS:

Front of Test Panel (Bumper, Rear Wall, Etc.,) SHOT ID ON LEFT

Rear of " " " " " " " ON RIGHT

UDRI TARGETS

A. Piekutowski 24 Feb 94

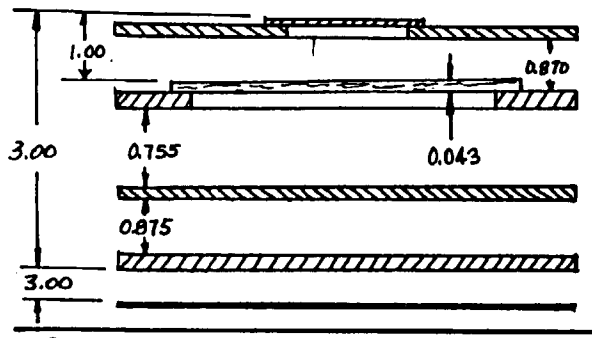


ASSEMBLY

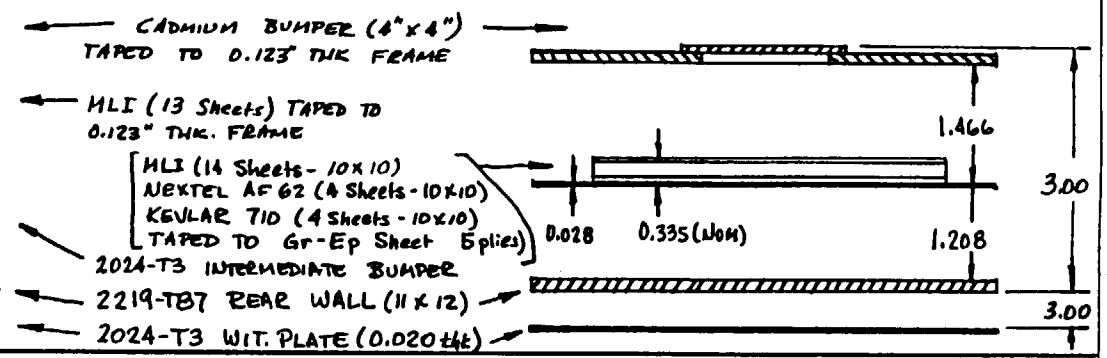
All Thread (Tightened against sheets)

TARGET DETAILS / DIMENSIONS

ALL-ALUMINUM



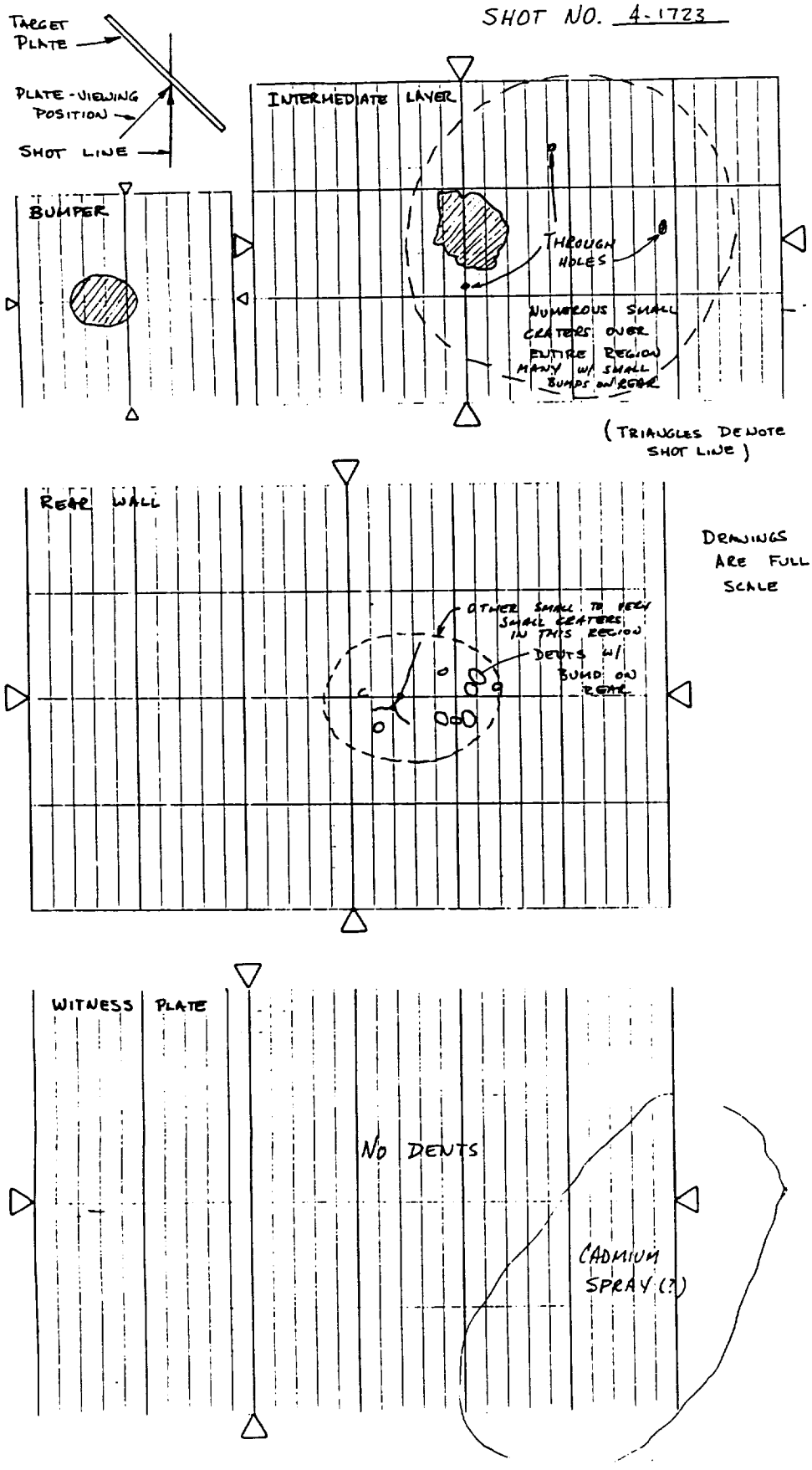
MOD 2

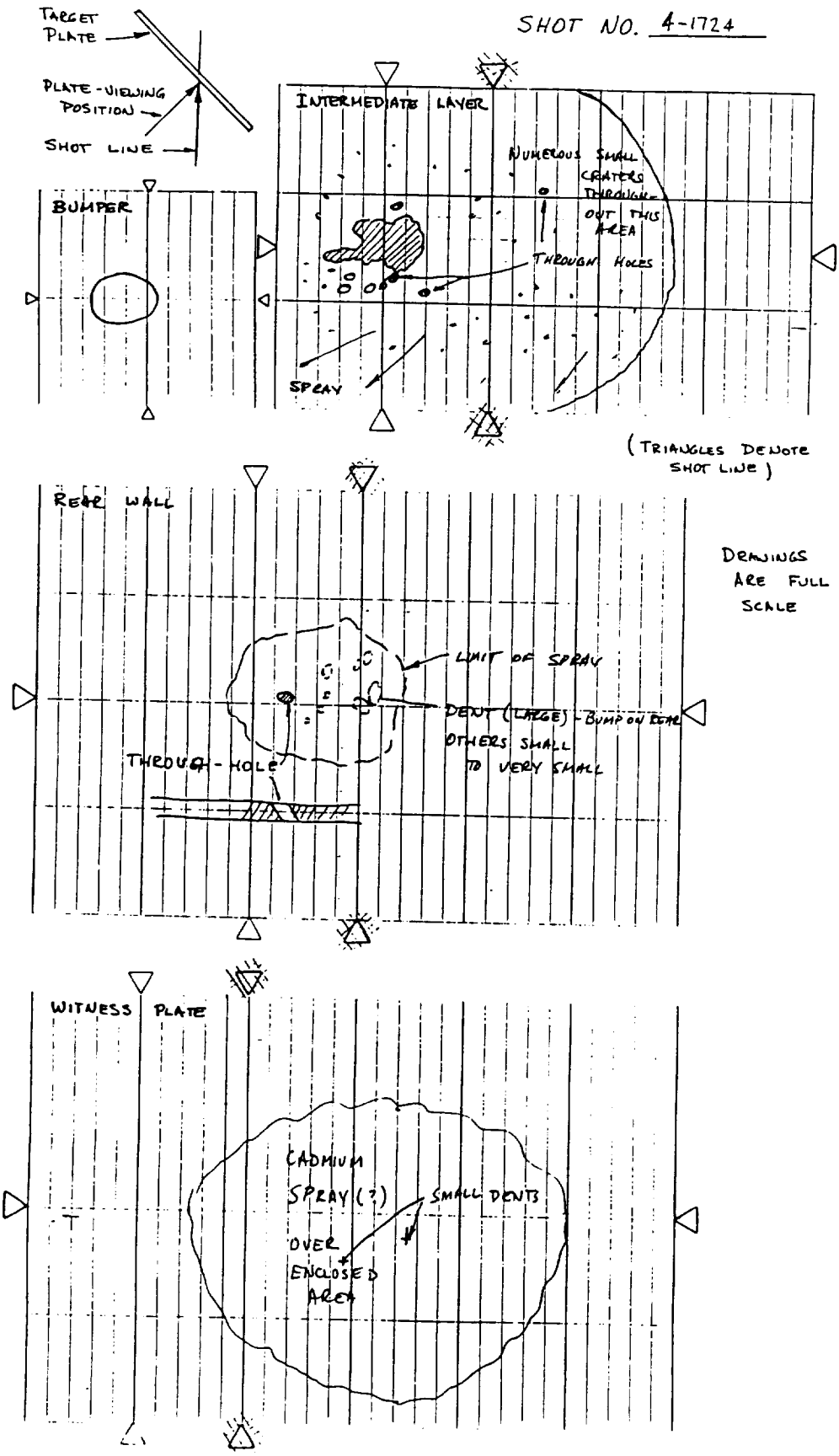


Shot Number	Cadmium Bumper	2024-T3 Aluminum	2219-T87 Aluminum	Cadmium Bumper	Gr-Ep Panel No.	2219-T87 Aluminum
4-1723	0.0470	0.0795	0.1265	—	—	—
4-1724	0.0475	0.0795	0.1260	—	—	—
4-1725 [a]	—	—	—	0.0475	#1-1 [a]	0.1262
4-1726	—	—	—	0.0472	#1-2	0.1260
4-1727	0.0472	0.0790	0.1260	—	—	—
4-1728	0.0471	0.0790	0.1266	—	—	—
4-1729	0.0471	0.0790	0.1260	—	—	—
4-1730	—	—	—	0.0470	#1-31	0.1260
4-1731	0.0468	0.0792 (Cadmium)	0.1260	—	—	—
4-1732	0.0470	0.0790 (Cadmium)	0.1260	—	—	—

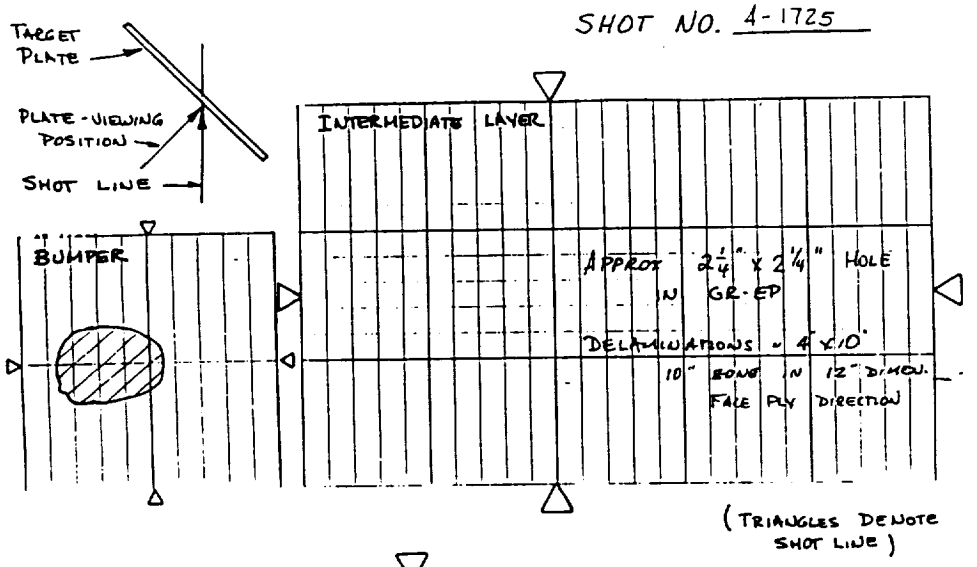
[a] Spacers were reversed for this test (i.e., Stuffing was 0.258" closer to Bumper than it should have been)

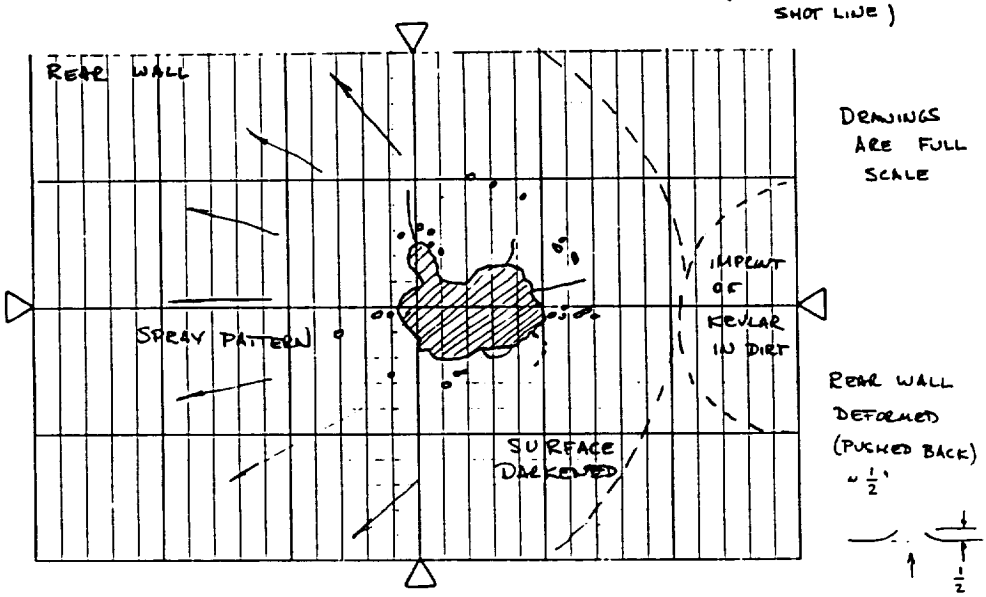
SHOT NO. 4-1723

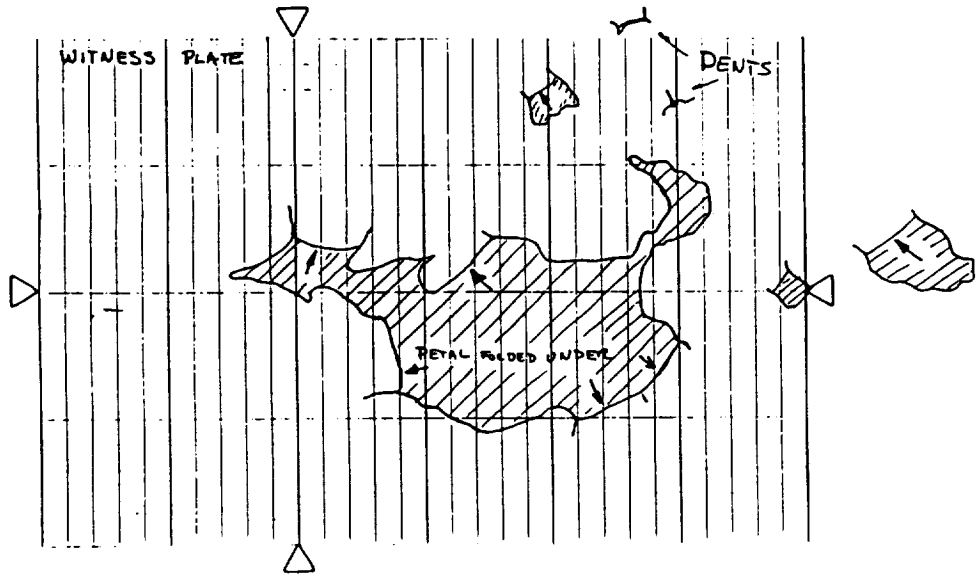


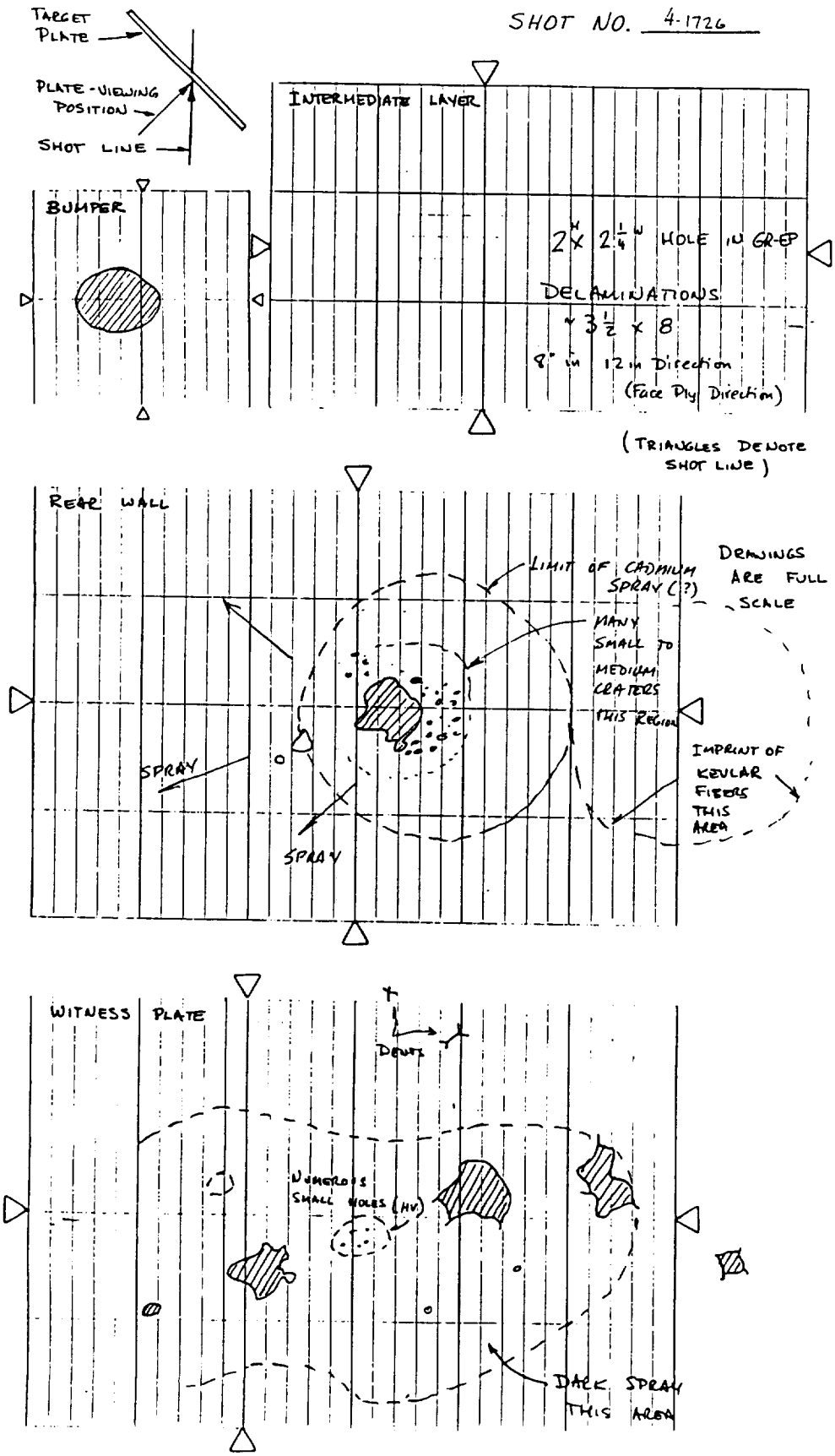

SHOT NO. 4-1724
TARGET PLATE
PLATE-VIEWING POSITION
SHOT LINE
INTERMEDIATE LAYER
NUMEROUS SMALL CRATERS THROUGHOUT THIS AREA
THROUGH HOLES
BUMPER
SPRAY
(TRIANGLES DENOTE SHOT LINE)
REAR WALL
DRAWINGS ARE FULL SCALE
LIMIT OF SPRAY
DENT (LARGE) - BUMP ON EDGE
OTHERS SMALL TO VERY SMALL
THROUGH-HOLE
WITNESS PLATE
CADMIUM SPRAY (?)
SMALL DENTS
OVER ENCLOSED AREA

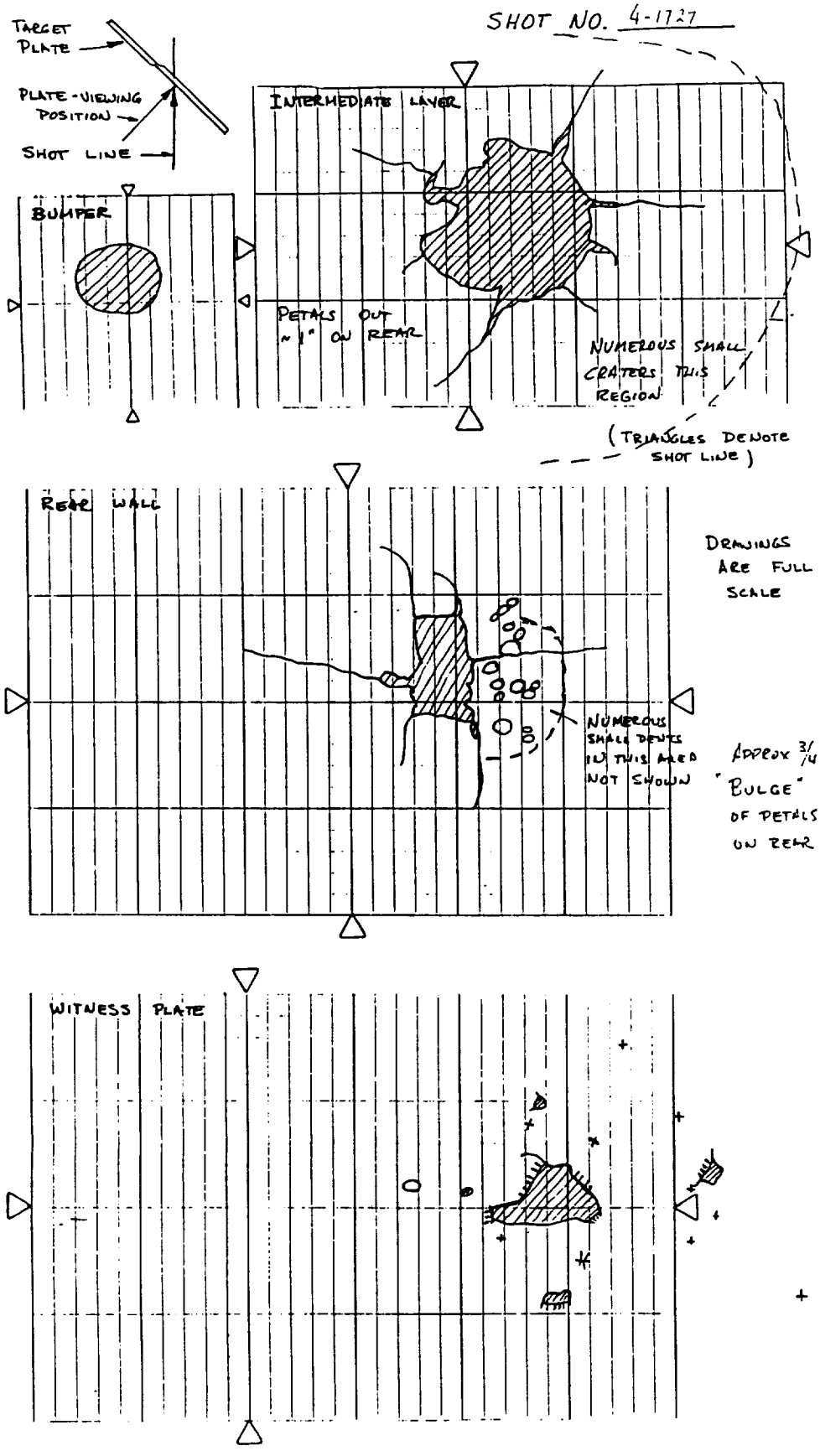
SHOT NO. 4-1725

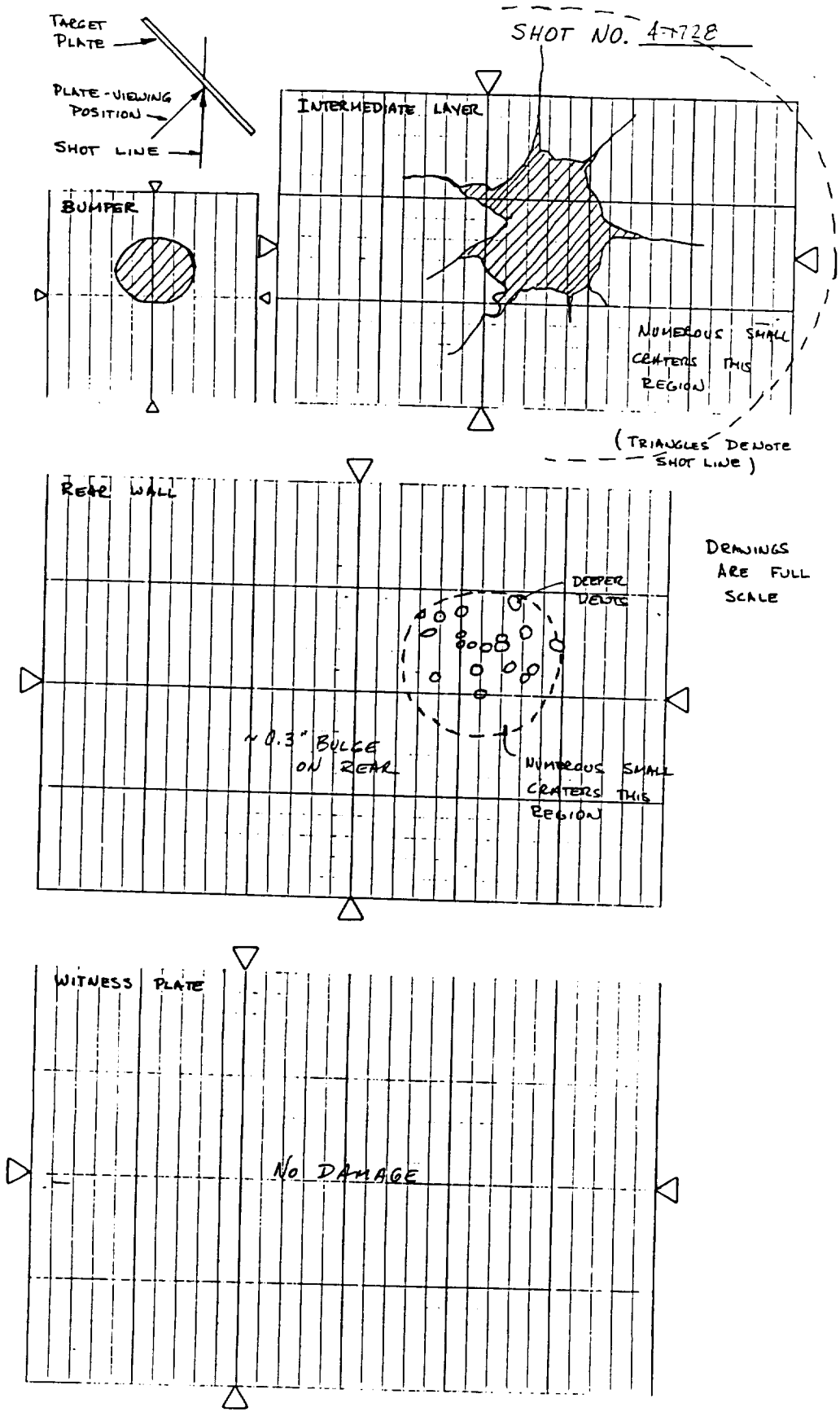


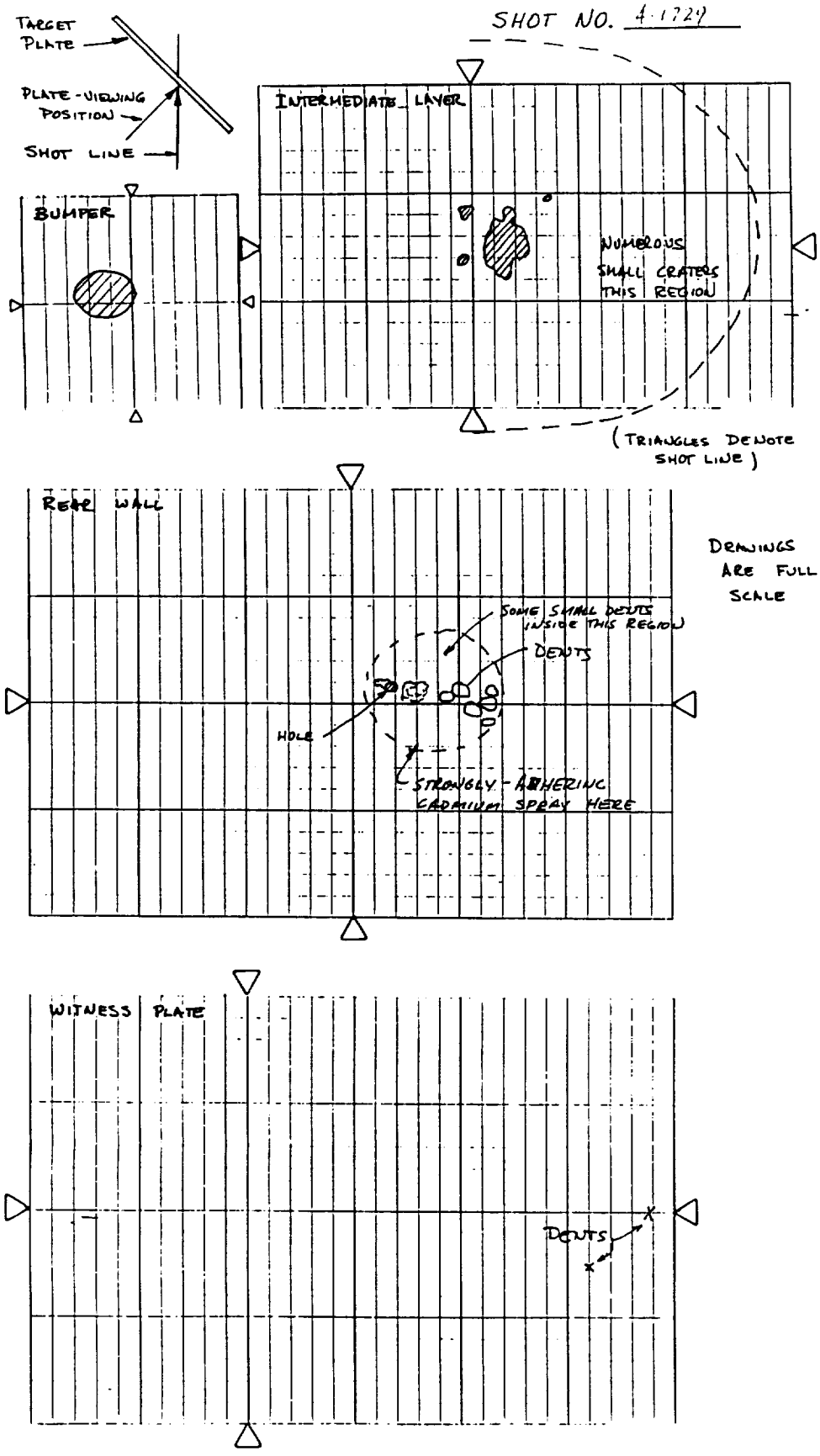


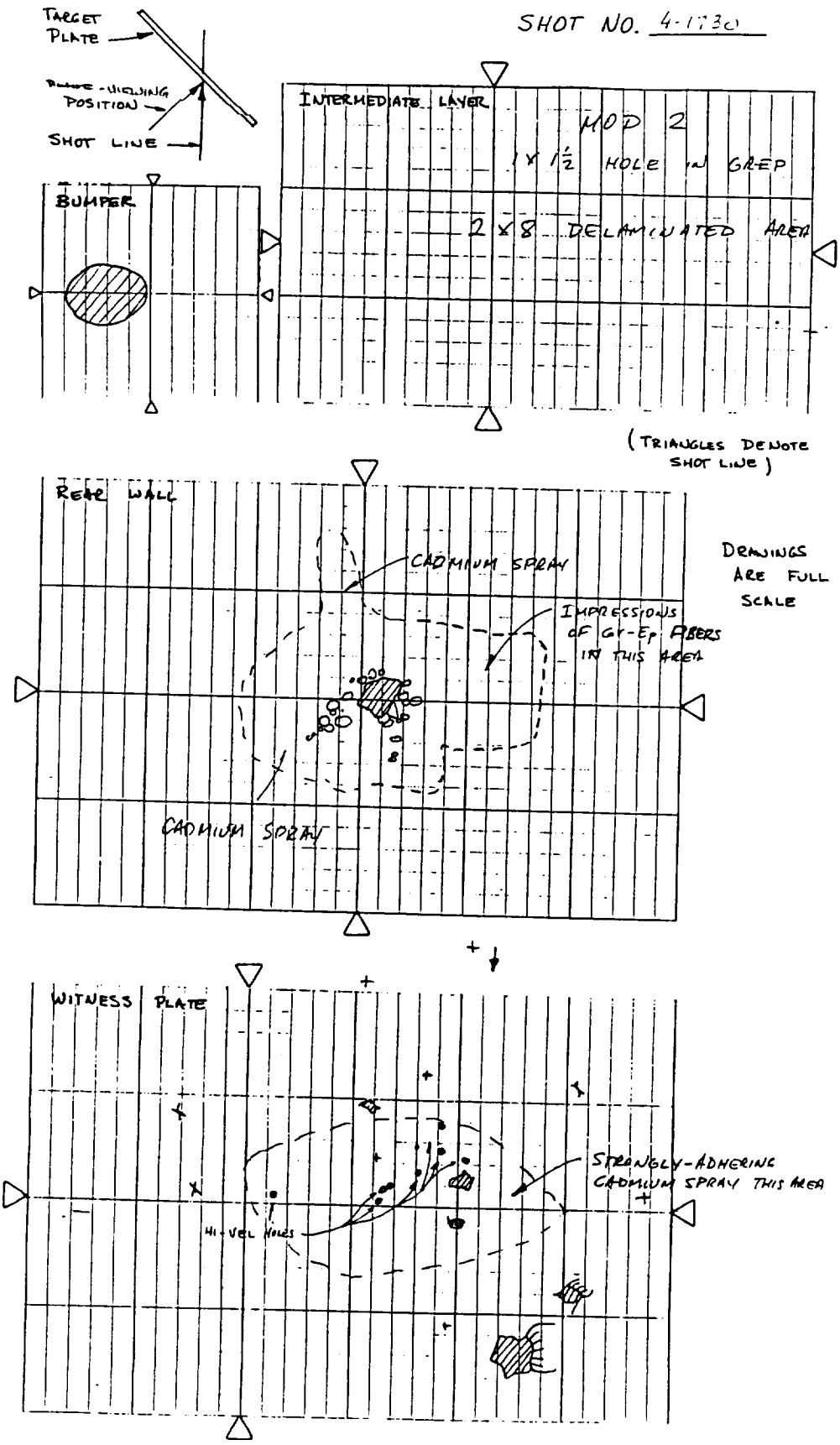



SHOT NO. 4-1726
TARGET PLATE
PLATE-VIEWING POSITION
SHOT LINE
INTERMEDIATE LAYER
BUMPER
2" X 2 1/4" HOLE IN GR-EP
DELAMINATIONS
3 1/2 X 8
8" in 12 in Direction
(Face Ply Direction)
(TRIANGLES DENOTE SHOT LINE)
REAR WALL
LIMIT OF CADMIUM SPRAY (?)
MANY SMALL TO MEDIUM CRATERS THIS REGION
DRAWINGS ARE FULL SCALE
SPRAY
SPRAY
IMPRINT OF KEVLAR FIBERS THIS AREA
WITNESS PLATE
DENTS
NUMEROUS SMALL HOLES (HV)
DARK SPRAY THIS AREA

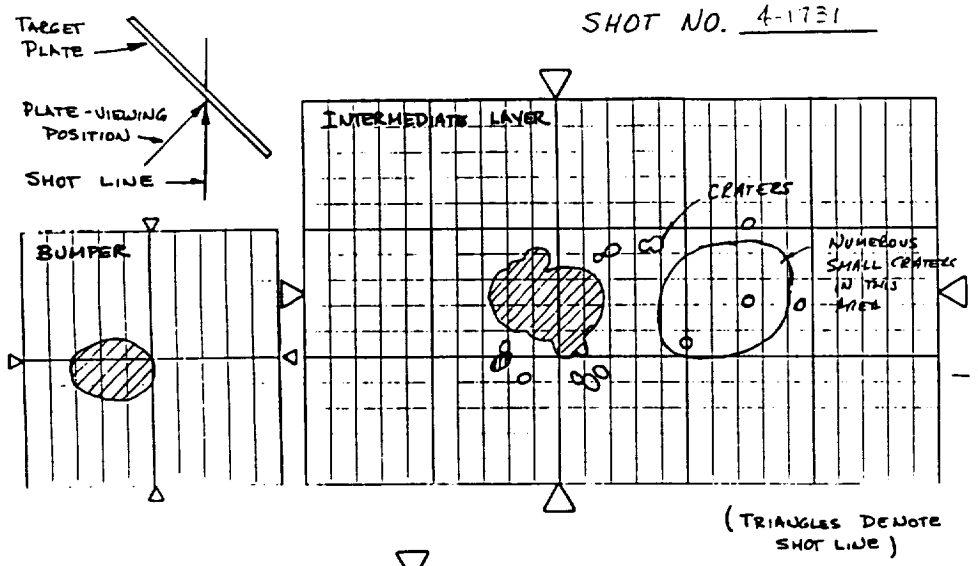

SHOT NO. 4-1727
TARGET PLATE
PLATE-VIEWING POSITION
SHOT LINE
BUMPER
INTERMEDIATE LAYER
PETALS OUT ~1" ON REAR
NUMEROUS SMALL CRATERS THIS REGION
(TRIANGLES DENOTE SHOT LINE)
REAR WALL
DRAWINGS ARE FULL SCALE
NUMEROUS SMALL DENTS IN THIS AREA NOT SHOWN
APPROX 3/4" "BULGE" OF PETALS ON REAR
WITNESS PLATE

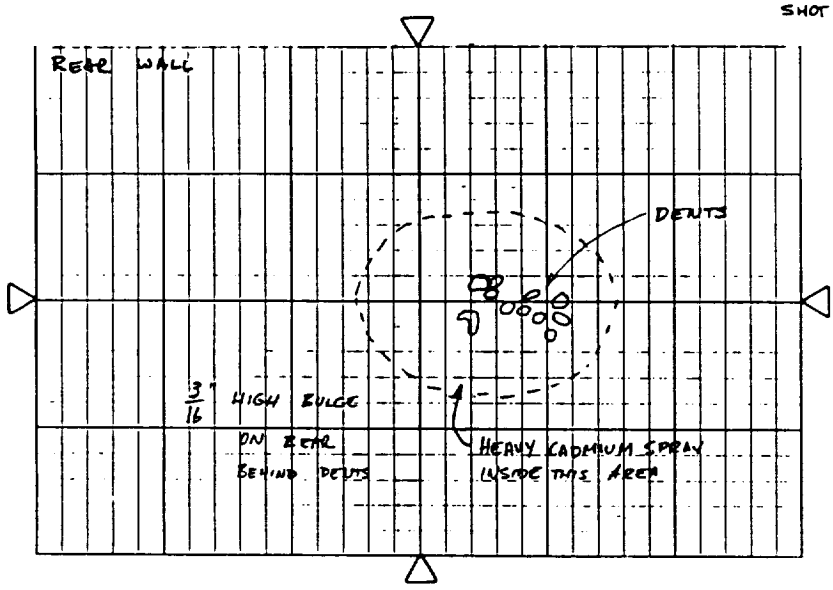

SHOT NO. 4-1728
TARGET PLATE
PLATE-VIEWING POSITION
SHOT LINE
INTERMEDIATE LAYER
BUMPER
NUMEROUS SMALL CRATERS THIS REGION
(TRIANGLES DENOTE SHOT LINE)
REAR WALL
DEEPER DENTS
~0.3" BULGE ON REAR
NUMEROUS SMALL CRATERS THIS REGION
DRAWINGS ARE FULL SCALE
WITNESS PLATE
NO DAMAGE


SHOT NO. 4-1724
TARGET PLATE
PLATE-VIEWING POSITION
SHOT LINE
INTERMEDIATE LAYER
BUMPER
NUMEROUS SMALL CRATERS THIS REGION
(TRIANGLES DENOTE SHOT LINE)
REAR WALL
DRAWINGS ARE FULL SCALE
SOME SMALL DENTS INSIDE THIS REGION
DENTS
HOLE
STRONGLY-ADHERING CADMIUM SPRAY HERE
WITNESS PLATE
DENTS

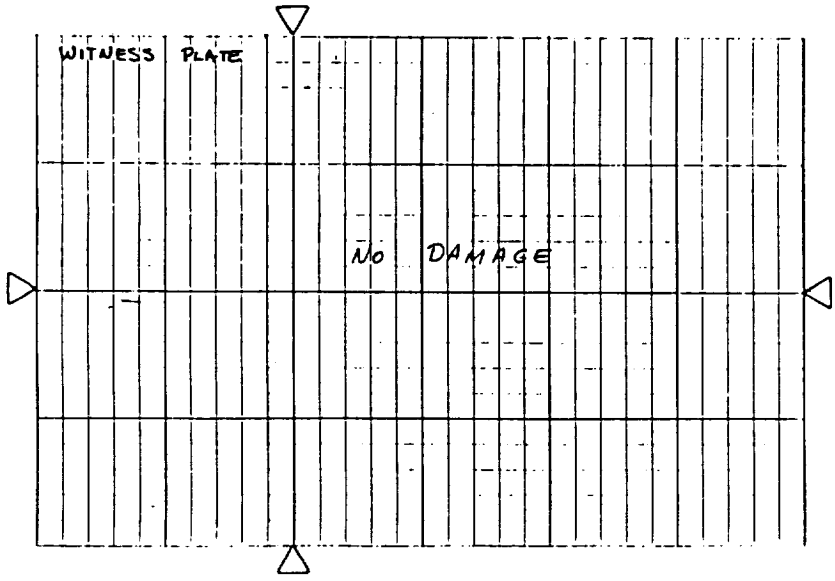

SHOT NO. 4-1730
TARGET PLATE
PLATE-HOLDING POSITION
SHOT LINE
INTERMEDIATE LAYER
MOP 2
1 X 1½ HOLE IN GREP
BUMPER
2 X 8 DELAMINATED AREA
(TRIANGLES DENOTE SHOT LINE)
REAR WALL
CADMIUM SPRAY
IMPRESSIONS OF Gr-Ep FIBERS IN THIS AREA
CADMIUM SPRAY
DRAWINGS ARE FULL SCALE
WITNESS PLATE
STRONGLY-ADHERING CADMIUM SPRAY THIS AREA
HI-VEL HOLES

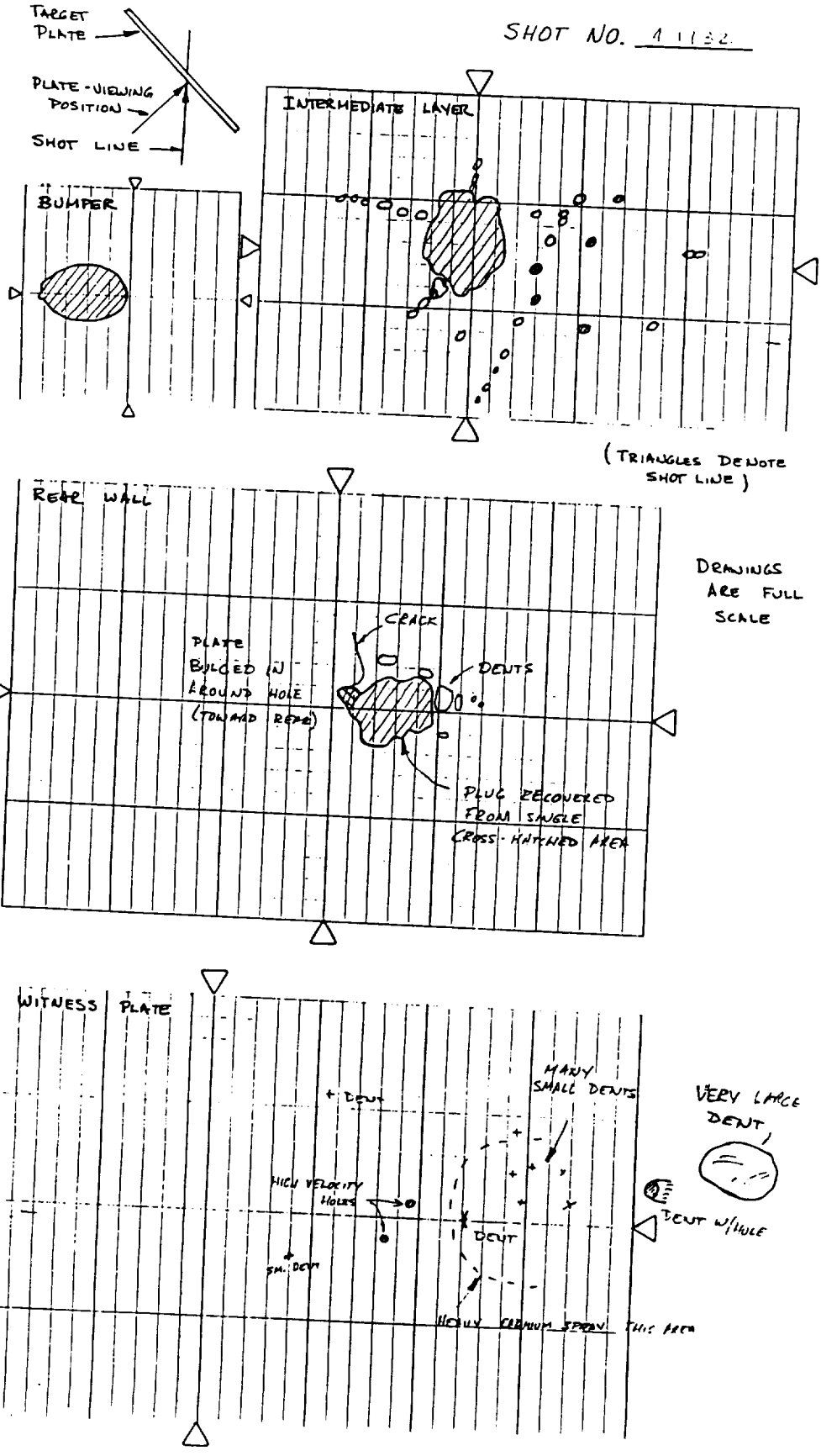
SHOT NO. 4-1731





DRAWINGS ARE FULL SCALE




TARGET PLATE
PLATE-VIEWING POSITION
SHOT LINE
SHOT NO. 41132
INTERMEDIATE LAYER
BUMPER
(TRIANGLES DENOTE SHOT LINE)
REAR WALL
DRAWINGS ARE FULL SCALE
CRACK
PLATE BULGED IN AROUND HOLE (TOWARD REAR)
DENTS
PLUG RECOVERED FROM SINGLE CROSS-HATCHED AREA
WITNESS PLATE
+ DENT
MANY SMALL DENTS
VERY LARGE DENT
HIGH VELOCITY HOLES
DENT W/HOLE
DENT
SM. DENT

REVIEW OF CADMIUM-ALUMINUM SCALING

1. BOEING uses a scaling factor of 3.1 for impact velocity.

Holsapple (1993) has investigated both static and dynamic values of the energy required for heat to melt, melt, heat from melt to vaporization, and vaporization for cadmium and aluminum. His results based on CTH computations for the square root of these energy ratios, i.e., $\sqrt{H_{i,Al} / H_{i,Cd}}$, is typically 3.1±0.1. A value of 3.1 is adopted here. As a consequence, an experiment with cadmium at 7 km/s produces the same scaled velocity as an impact on an aluminum shield at about 22 km/s.

From:
J. Spacecraft Rockets
Vol 31 No 5, pp 866-877, 1994

CADMIUM SIMULATIONS OF ORBITAL DEBRIS SHIELD PERFORMANCE TO 18 KM/S.

ROBERT M. SCHMIDT, KEVIN R. HOUSEN,
Boeing Defense & Space Group, M/S 87-60, Seattle, WA 98124

ANDREW J. PIEKUTOWSKI and KEVIN L. POORMON
University of Dayton Research Institute, 300 College Park, Dayton OH 45469

Holsapple Reference →

HYPERVELOCITY IMPACT EXPERIMENTS IN SURROGATE MATERIALS

K. A. HOLSAPPLE

Aeronautics and Astronautics FS-10, University of Washington, Seattle, WA 98195;
Consultant, Boeing Defense and Space Group, Seattle, WA

Int. J. Impact Engng.
Vol 14, pp 335-345, 1993

The scaling determined by that comparison of the reference points and the points "E"; as well as certain other significant points can be determined by a comparison of the ratios of the internal energy (velocity scale squared) and the mass densities at those key points on these figures. An exact match of scaled properties would give a single velocity and mass density scale for all points considered. The actual scale factors based on a number of those points is shown in the Table 2 for the implied velocity scales, and in Table 3 for the implied mass density scales. The static properties are those found in handbooks for properties at one atmosphere pressure in quasi-static processes. The dynamic properties are determined by the Hugoniot curve, which governs the shock propagation in the material.

Table 2. Ratios of Energy Properties for Aluminum, Cadmium and Zinc, and the Resulting Velocity Scale Factors. (Energies are ergs/gm, sound speed in km/sec.)

	Alum	Cad	Zinc	Ratio Al/Cd	Vel. Ratio	Ratio Al/Zn	Vel. Ratio
STATIC PROPERTIES							
Energy to Begin Melt	6.40E+09	7.10E+08	1.60E+09	9.0	3.0	4.0	2.0
Heat of Fusion	4.00E+09	5.50E+08	1.13E+09	7.3	2.7	3.5	1.9
Energy to Begin Vaporization	1.06E+10	1.92E+09	4.59E+09	5.5	2.3	2.3	1.5
Vapor Energy	1.19E+11	1.00E+10	2.00E+10	11.9	3.4	6.0	2.4
Reference Sound Speed	5.3	2.48	3.03		2.13		1.75
DYNAMIC PROPERTIES							
Energy for Some Melt on Unloading (Point A)	3.90E+10	3.90E+09	9.60E+09	10.0	3.2	4.1	2.0
Energy for Complete Melt on Unloading (Point B)	6.20E+10	7.00E+09	1.52E+10	8.9	3.0	4.1	2.0
Energy to Begin Melt at Shock (Point C)	1.34E+11	1.30E+10	1.24E+10	10.3	3.2	10.8	3.3
Energy to Vaporize Some on Unloading (Point D)	1.42E+11	1.20E+10	2.41E+10	11.8	3.4	5.9	2.4
Energy to Completely Melt at Shock (Point E)	1.52E+11	1.50E+10	1.61E+10	10.1	3.2	9.4	3.1

Table 3. Ratios of Mass Density Properties for Aluminum, Cadmium and Zinc.

	Alum	Cad	Zinc	RatioAl/ Cd	Ratio Al/Zn
STATIC PROPERTIES					
Initial Mass Density	2.70	8.648	7.13	3.20	2.64
Mass density at Melt Beginning	2.57	8.42	6.84	3.28	2.66
Mass Density at Complete Melt	2.38	8.02	6.60	3.37	2.77
Mass Density at Vaporization Beginning	2.15	7.73	6.24	3.59	2.90
DYNAMIC PROPERTIES					
Mass Density at Hugoniot Point A	3.87	11.12	9.49	2.87	2.45
Mass Density at Hugoniot Point B	4.12	11.79	9.98	2.86	2.42
Mass Density at Hugoniot Point C	4.61	12.64	9.74	2.74	2.11
Mass Density at Hugoniot Point D	4.65	12.39	10.52	2.67	2.26
Mass Density at Hugoniot Point E	4.69	12.82	10.04	2.74	2.14

With regard to the internal energy and the implied velocity scales in Table 2, it is seen that all energy ratios are much more consistent for the dynamic properties than for the purely static properties. Furthermore, they are all quite different than the simple reference-value sound speeds. Insofar as that sound speed value is determined by the initial slope of an isentrope at the reference conditions, it is not particularly indicative of the global behavior. Thus, it is probably not the best measure to determine the effective velocity scaling. All dynamic energy scales give effective velocity scales of about *1:3.1* for cadmium, with variations within 10%. There is much more spread for zinc, centering around about *1:2.5*.

Because the density ratio of Cadmium to 2017 Aluminum is 3.1, it is incidental that the scaled (Cadmium) tests have the same projectile momentum as the actual aluminum tests

$\rho_{Cd} = 8.648\ g/cm^3$, $\rho_{2017\,Al} = 2.791\ g/cm^3$

$$\frac{8.648}{2.791} = 3.098$$

Projectile kinetic energies are not the same for these tests. Consequently, Scaling of Cad/Aluminum tests using a scaling factor of 3.1 is equivalent to momentum scaling.

2. Proposed Scaling Technique

(a) Scaling factor (to be applied to impact velocities) will be determined empirically. It will be the ratio of the impact velocities of similar tests which used cadmium spheres and bumper sheets and aluminum spheres and bumper sheets. The tests will be similar in the regard that the bumper-thickness-to-projectile-diameter ratio, t/D, is the same and the debris-cloud shapes, velocities, etc., are similar

(b) Scaling factor will be determined from tests performed with normal incidence. It is assumed that fracture and fragmentation in the tests described in (a) are produced by stresses which are similar for similar test geometries. It is further assumed that fracture and fragmentation of a sphere during oblique impact are also geometrically similar

(c) Momentum of actual and scaled projectile will be the same. Mass of scaled projectile (cadmium) will be determined using the scaled impact velocity and the momentum of the aluminum projectile.

(d) t/D ratios of scaled and actual test will be preserved.

(e) With the exception of the bumper thickness, all target components and component spacings for the scaled target will be the same as for the actual target.

3. Determination of Scaling Factor (For Impact Velocity)

(a) Debris clouds for appropriate aluminum and cadmium tests will be compared quantitatively. Data from aluminum tests are considered to be the "standard."

(b) Data for tests with t/D ratios of 0.160 to 0.168 are available. Normalized velocity data describing the motion of the leading edge, V_1/V_0, the trailing edge, V_4/V_0, and the major diameter of the debris cloud, $V_{9\text{-}10}/V_0$, were compared. The values of measured points from the cadmium tests (at 2.27 km/s and 3.36 km/s) were placed at the appropriate places on curves developed using the aluminum test data plotted as normalized velocity vs. impact velocity. (See Figs. 6b and 7b in my 1992 HVIS paper for reference) The aluminum impact velocity at the location of the cadmium normalized velocity (as placed on the aluminum curve) was divided by the cadmium impact velocity to obtain a velocity ratio (scaling factor). Values thus obtained are as follows:

Point ① - leading edge

Slope of curve is very low

Velocity ratios could

easily range from 1.8

to 2.4 for both cadmium

tests $V_0 = 2.27$ and 3.36

(because curve nearly

horizontal, not error

in measurements)

Point ④ - Trailing Edge

$\frac{4.75}{2.27} = 2.09$

$\frac{7.5}{3.36} = 2.23$

Points 9-10 - Diameter

Curve very steep

for lower velocity

Cadmium

Ranges from 1.9 to 2.1

$\frac{7.65}{3.36} = 2.28$

3. Continued

(b) Continued.

A scaling factor of 2.25 was arbitrarily chosen. Arguments could be made for a value of 2.13 or so based on the ratio of the materials' sound speeds. This factor (2.13) could also "work" for the range of ratios presented at the end of the previous page.

(c) Using conditions of B 563, 17/64-in-diameter, 2017-T4 aluminum sphere at 6.96 km/s, determine mass of cadmium sphere to be used in scaled test.

$$V_{scaled} = 6.96 \div 2.25 = 3.09 \text{ km/s}$$

$$m_{scaled} = \frac{m_{alum} \times V_{alum}}{V_{scaled}} = \frac{0.445 \times 6.96}{3.09} = 1.0113 \text{ g}$$

$$\text{Diameter}_{scaled} = 2r \qquad r = \left(\frac{3 m_{scaled}}{4\pi \rho_{cad}}\right)^{1/3} = 0.1194 \text{ in}$$

$$\text{Diameter}_{scaled} = 0.2388 \text{ in}$$

$$\text{Thickness of scaled bumper} = \left(\frac{t}{D}\right)_{alum} \times \text{Diameter}_{scaled}$$

$$t/D_{alum} = \frac{0.047}{0.266} = 0.177$$

$$\text{Thickness of scaled bumper} = 0.177 \times 0.2388$$
$$= 0.0422 \text{ in}$$

(d) Scaled Test Conditions

0.239-in-diameter Cadmium Sphere at 0.0422-in-thick Cadmium bumper. Remainder of target = "Normal" two-thirds scale all-aluminum target. $V_0 = 3.09$ km/s

4. Some other Comparisons

(a) Compare radiographs as follows

T4-1717 3/8" Aluminum sphere @ 4.96 km/s t/D = 0.168

S4-1443 5/16" Cadmium sphere @ 2.27 km/s t/D = 0.160

$\frac{4.96}{2.27} = 2.18$ Scaling Factor nearly "ideal"

Points to observe:

- Cloud shapes qualitatively the same
- Fragment sizes and distribution about the same
- Good overall match

T4-1291 3/8" Aluminum sphere @ 6.71 km/s t/D = 0.163

T4-1427 5/16" Cadmium Sphere @ 3.36 km/s t/D = 0.160

$\frac{6.71}{3.36} = 2.00$ (Cadmium velocity too high or alum velocity too low)

Points to observe:

- Cloud shapes qualitatively the same, Some structure harder to see in cadmium cloud because cadmium is radiographically opaque
- Front of Cadmium cloud has melt evidenced by streams of droplets that are developing. Melt is incipient in aluminum cloud (See Fig 12 in my 1992 HVIS paper)
- Solid fragments form spall shell at rear of cadmium cloud

4. Continued

(a) Continued

Debris cloud dimensions (when compared at similar distances behind the bumper will differ only by the differences in the diameters of the original projectiles ($\frac{1}{16}$ in)

(b) Because cloud diameters are close to same, the momentum delivered per unit area of rear wall should be the same for the cadmium and the aluminum tests. The difference in the time of deposition will vary by the scaling factor

(c) The kinetic energy of the various projectiles will be significantly different.

Scale Factor	1.00 (Aluminum)	2.25	3.10
Kinetic Energy ($\frac{1}{2}mV^2$)	10.873	4.822	3.489

A. Piekutowski 22 Mar 94

"RATING" OF CAD-AL AND CAD-CAD TESTS AT UDRI

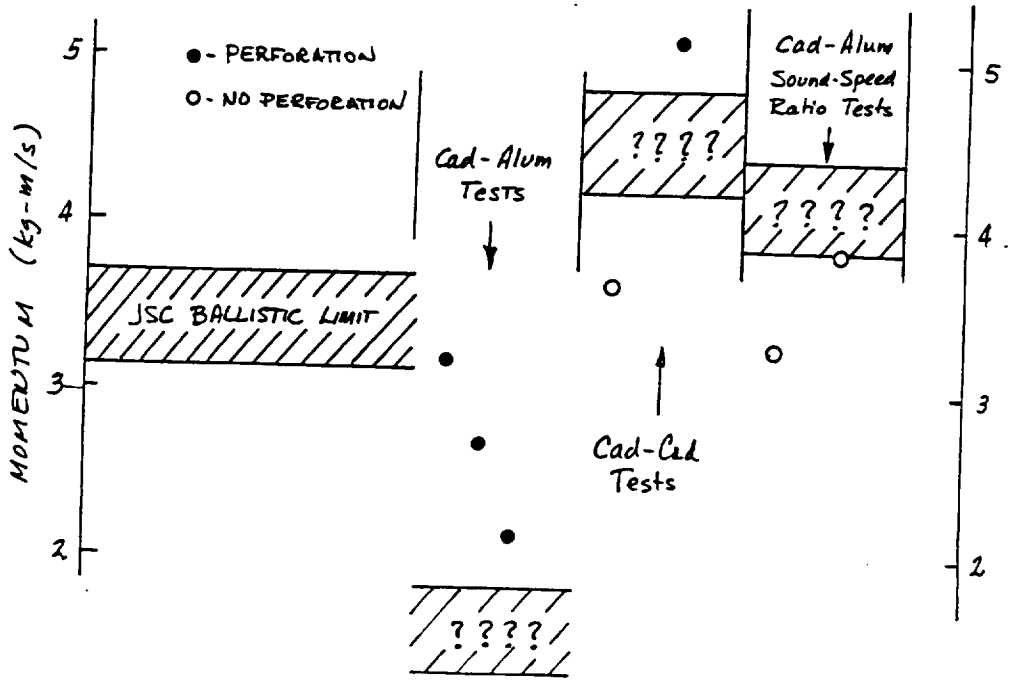
Compare results (P vs NP) on basis of projectile momentum (for actual projectile & Velocity-Alum ≥ 7 km/s)

Use JSC Tests as "Standards"

NP	—	B563	17/64 Dia @ 6.96 km/s	3.125 kg-m/s
P	—	B560	9/32 Dia @ 6.94 km/s	3.692 kg-m/s

BALLISTIC LIMIT BETWEEN THESE VALUES

Shot No	Proj. Wt (g)	Velocity (km/s)	Momentum (kg-m/s)	Percent Over/Under	P/NP
		Cad-Alum Tests 3.1 Scale Factor on Impact Velocity			
4-1723	1.4005	2.28	3.193	+2.2	P
4-1724	1.1780	2.27	2.674	-14.4 (NP limit)	P
4-1729	0.9420	2.23	2.101	-32.8 (NP limit)	P
		Cad-Cad Test 3.1 Scale Factor on Impact Velocity			
4-1731	1.6469	2.22	3.656	+17.0 (NP Limit)	NP
4-1732	2.2944	2.23	5.116	+38.5 (P Limit)	P
		Cad-Alum Tests ~2.25 (Sound-Speed Ratio) Scale Factor on Impact Velocity			
4-1733	1.0063	3.21	3.230	+3.4 (NP Limit)	NP
4-1734	1.2110	3.15	3.815	+3.3 (P Limit)	NP



A. Piekutowski 23 Mar 94

Use of a 3.1 scaling factor and Cad-Alum is definitely a conservative test procedure for an all-aluminum shield test. We would have to assume the same conclusion extends to the 11 km/s (scaled) tests since this was our observation for the 7 km/s (scaled) tests. The same conclusion could be drawn for the Mod-2 tests at 7 km/s (scaled).

Use of a 3.1 scaling factor and Cad-Cad is a liberal test procedure. A third test, between the two shown on the preceding figure, would certainly help to quantify the degree of liberalism.

The sound-speed-ratio scaling tests also show this procedure is liberal and would benefit from a third test at higher momentum.

Failure of the rear walls in the JSC tests appeared to result from the impact of intermediate-wall fragments. Cad-Alum tests (scale factor = 3.1) showed failures due to impact of projectile fragments. Ample evidence of impact of intermediate-wall fragments was also evident. Cad-Cad (scale factor = 3.1) test 4-1732 showed two high-velocity-fragment holes in the witness plate (near the shot line), indicating lethal cadmium projectile fragments were still available after the intermediate wall was completely involved by the impact of the debris cloud. The combination of Cad-Cad for the all-aluminum shield may be a better scaled simulation, however. A similar scaling scheme (similar to cad-cad) does not seem possible for the Mod 2 shield.

Use of the sound-speed scaling procedure only requires a cadmium bumper and projectile. If this scaling procedure should be meaningful (and the ballistic limit for an all-aluminum shield would be near the JSC ballistic limit), this scaling procedure could be useful for evaluation of all-aluminum <u>and</u> Mod 2 shields at higher scaled velocities. Shape and normalized velocities of various points in the debris clouds are similar for two velocities -- 5 km/s and 6.7 km/s -- making extension to 11 km/s (scaled) not quite as big a "leap of faith."

Joel, I included 2 print of the crap in 4-733 and 4-1734

18 Mar 94.

Joel,

Sent 3/23/94

Following are the results of todays shot and values for Mondays shot

	B563	Nominal Scaled	4-1733
Scale Factor	1.00	2.25 2.13 2.00	2.17 (Close)
Impact Velocity, (km/s)	6.96	3.09 3.27 3.49	3.21 (Too Slow)
Projectile Mass, (g)	0.4490	1.0113 0.9557 0.898	1.0063 (Too Heavy)
Projectile Momentum, (mV)	3.125	3.125 3.125 3.125	3.230 (3.4% High)
Projectile Diameter, (in)	0.2656	0.2388 0.2344 0.2296	0.2384
Bumper Thickness, (in)	0.047	0.0422 0.0415 0.0406	0.0445 OK
t/D Ratio	0.177	0.177 0.177 0.177	0.174
Penetration / No Penetration	No P	—	No P

↳ More Scales test than current Scaled test

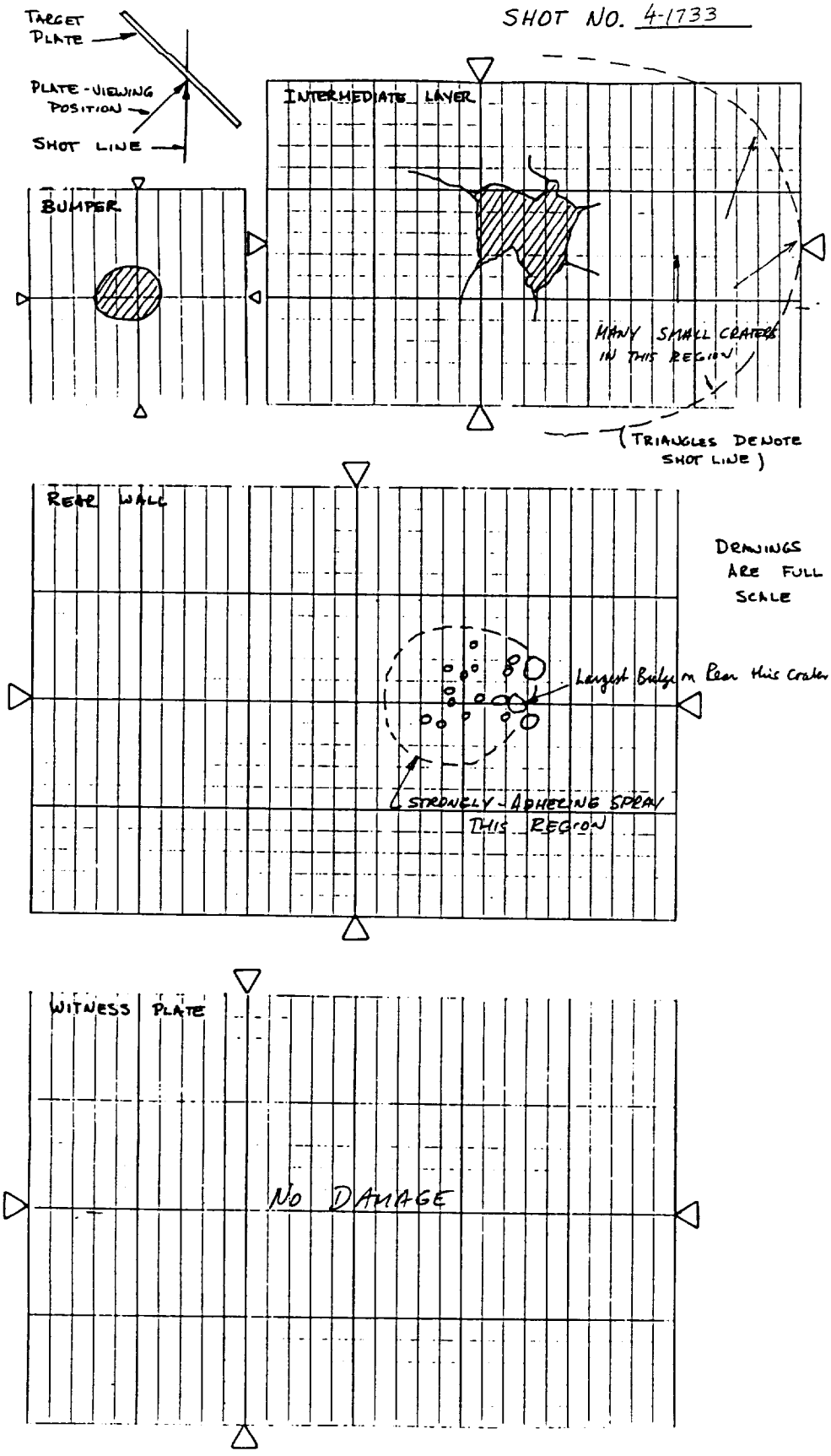
	B560-6.94 — (B562?)	Nominal Scaled	4-1734
Scale Factor	1.00	2.25 2.13 2.00	2.21
Impact Velocity (km/s)	6.96 (~~6.94~~ 6.94 Act)	3.09 3.26 3.48	3.15 Too Slow
Projectile Mass (g)	0.5321 (0.5326)	1.1985 1.1332 1.062	1.2110 Too Heavy
Projectile Momentum (mV)	3.703 (3.676)	3.703 3.696 3.515	3.815
Projectile Diameter (in)	0.2812	0.2528 0.2481 0.2478	0.2536 Too Big
Bumper Thickness (in)	0.047	0.0422 0.0414 0.0405	0.0420 Too Thick
t/D Ratio	0.167	0.167	0.166
Penetration / No Penetration	P	—	No P

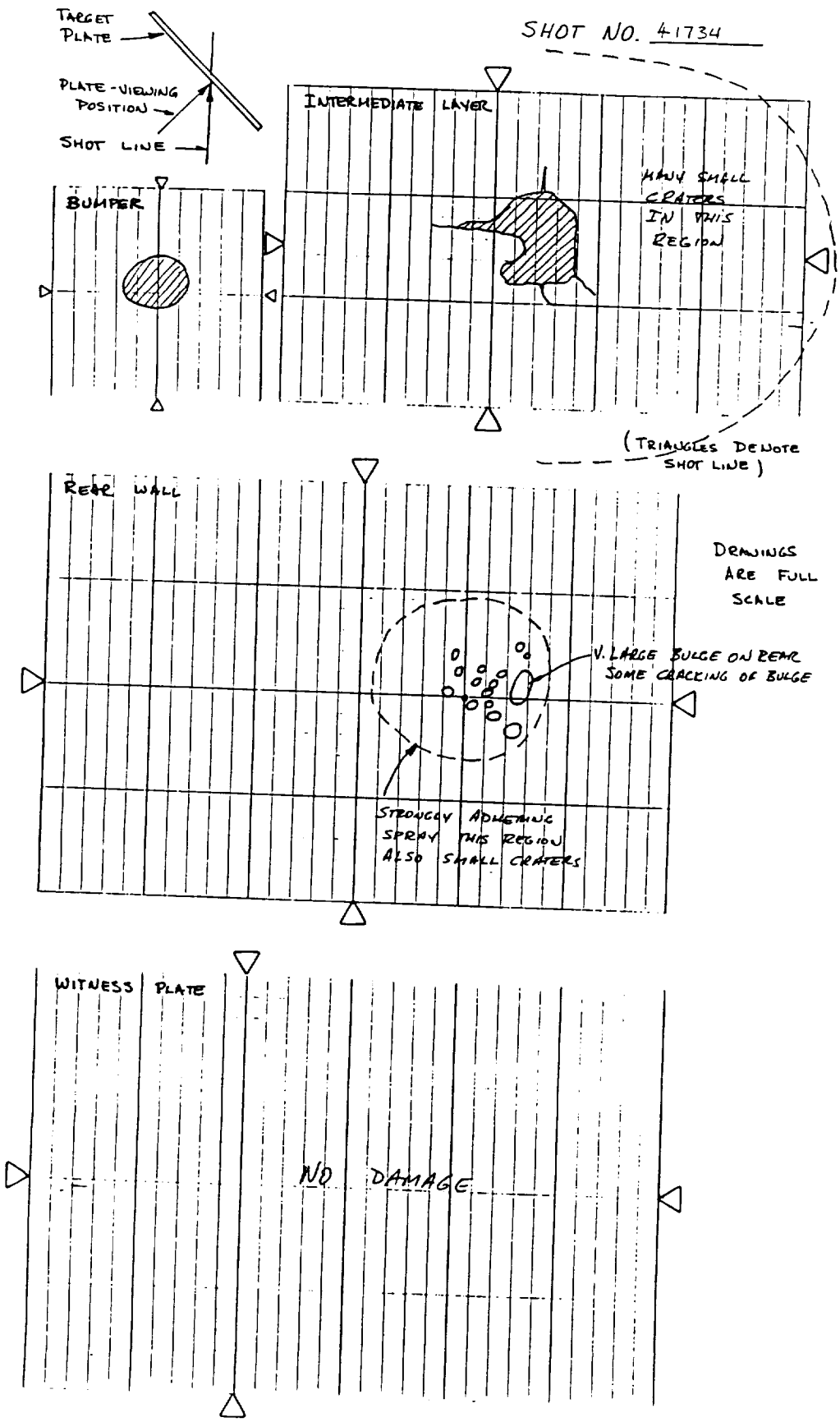
Next shot - Single Sheet 1mm Al and Fabric Blanket (0.25 cm/g)

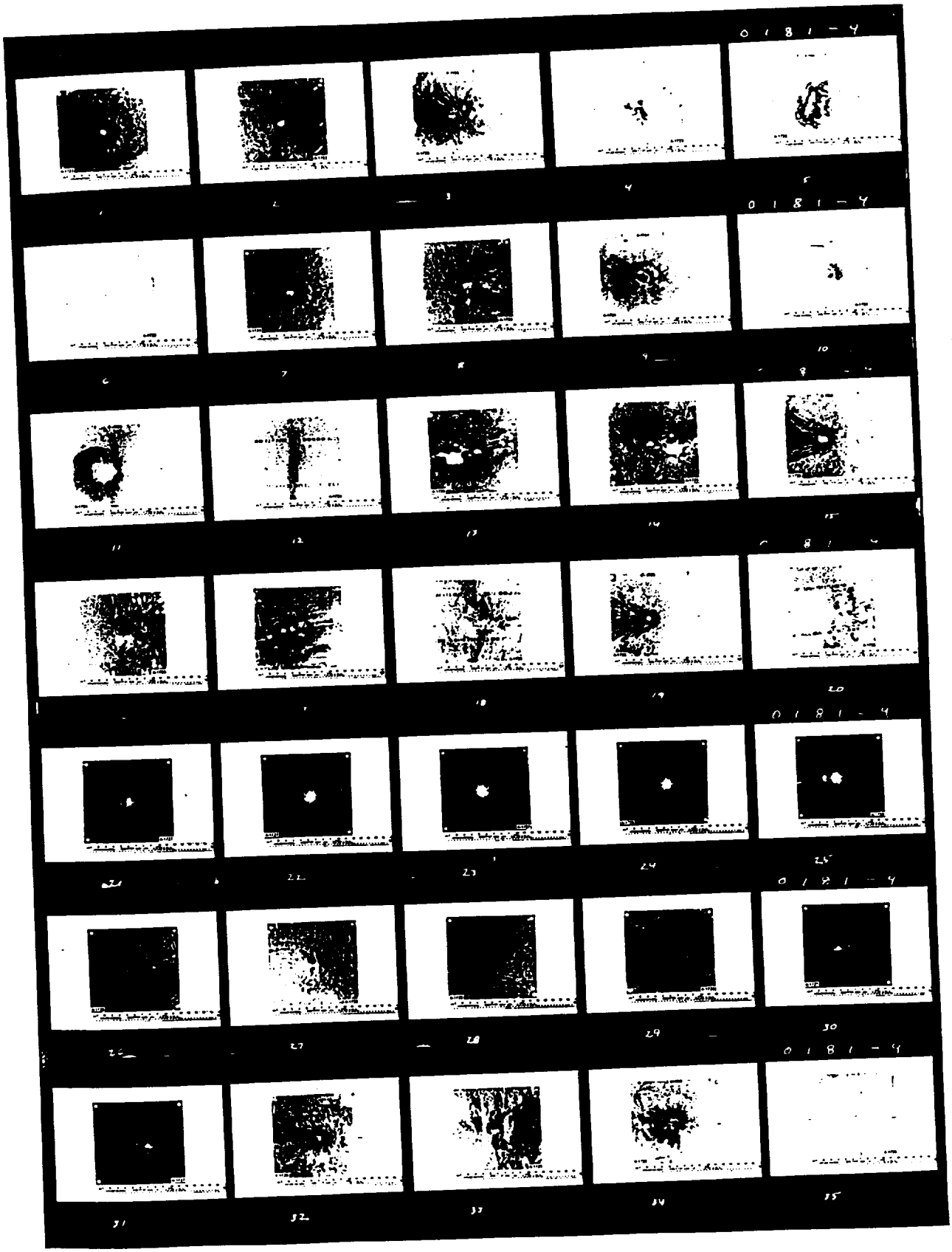
Let you know on the QT as soon as I have a test result.

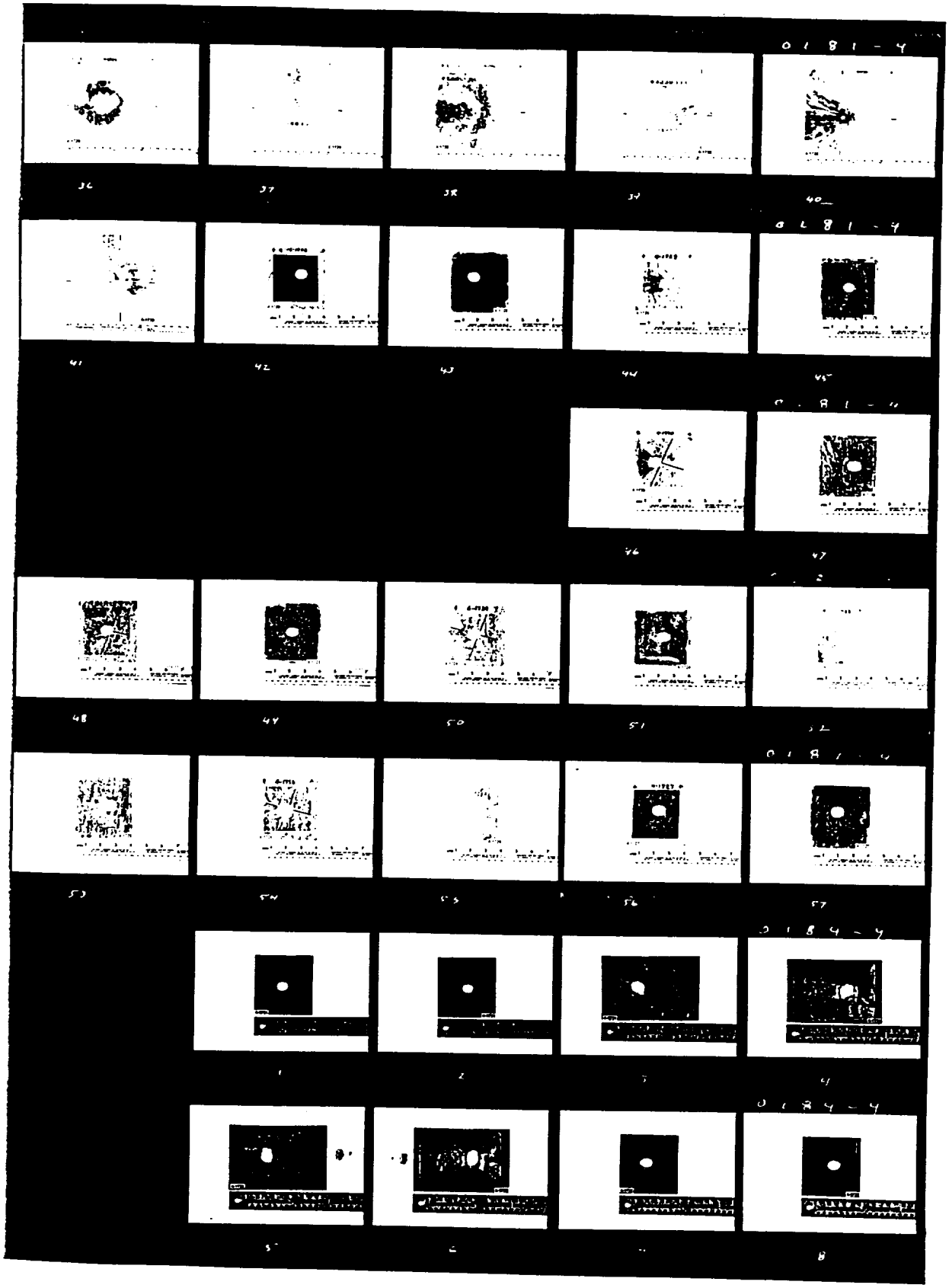
Andy

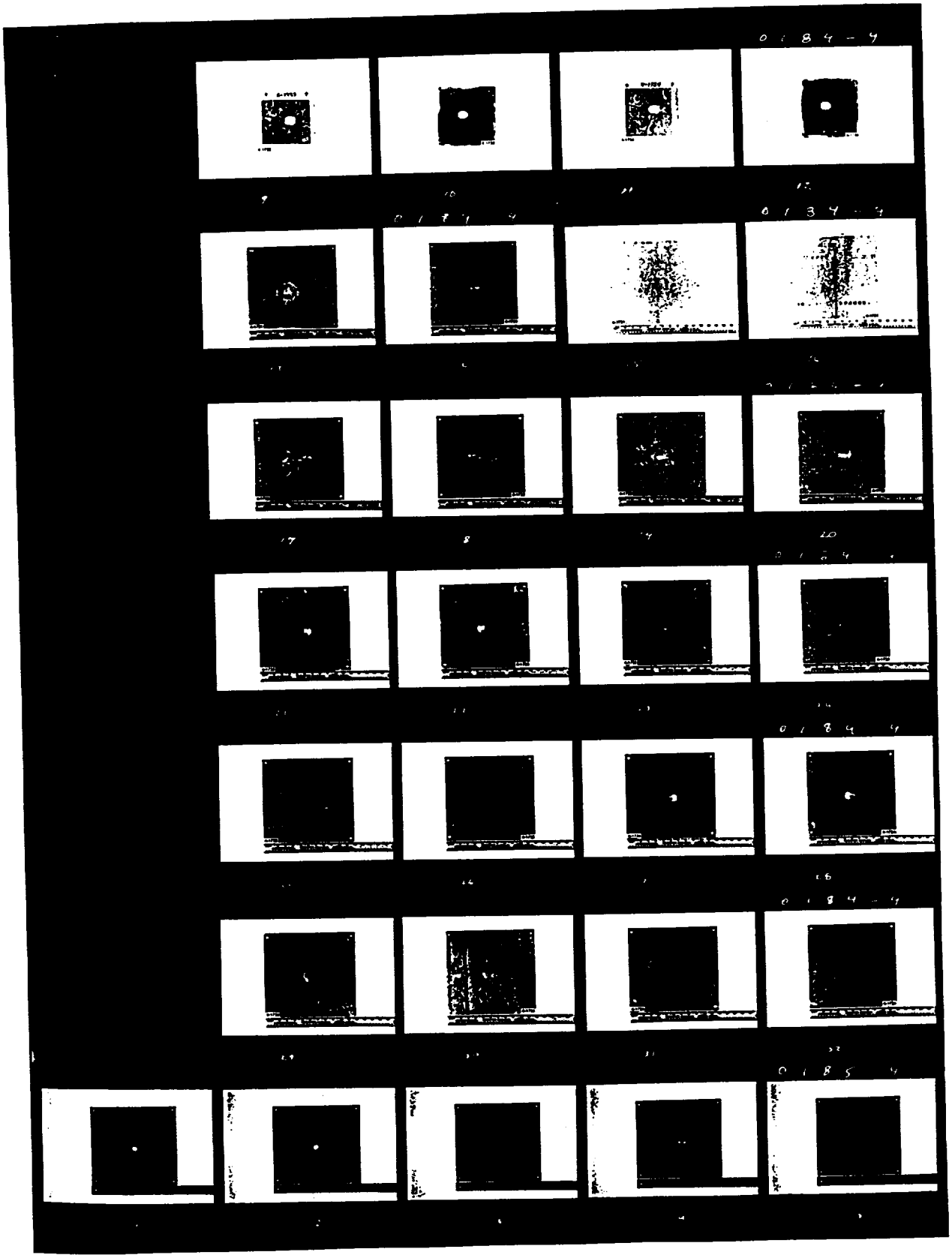
SHOT NO. 4-1733

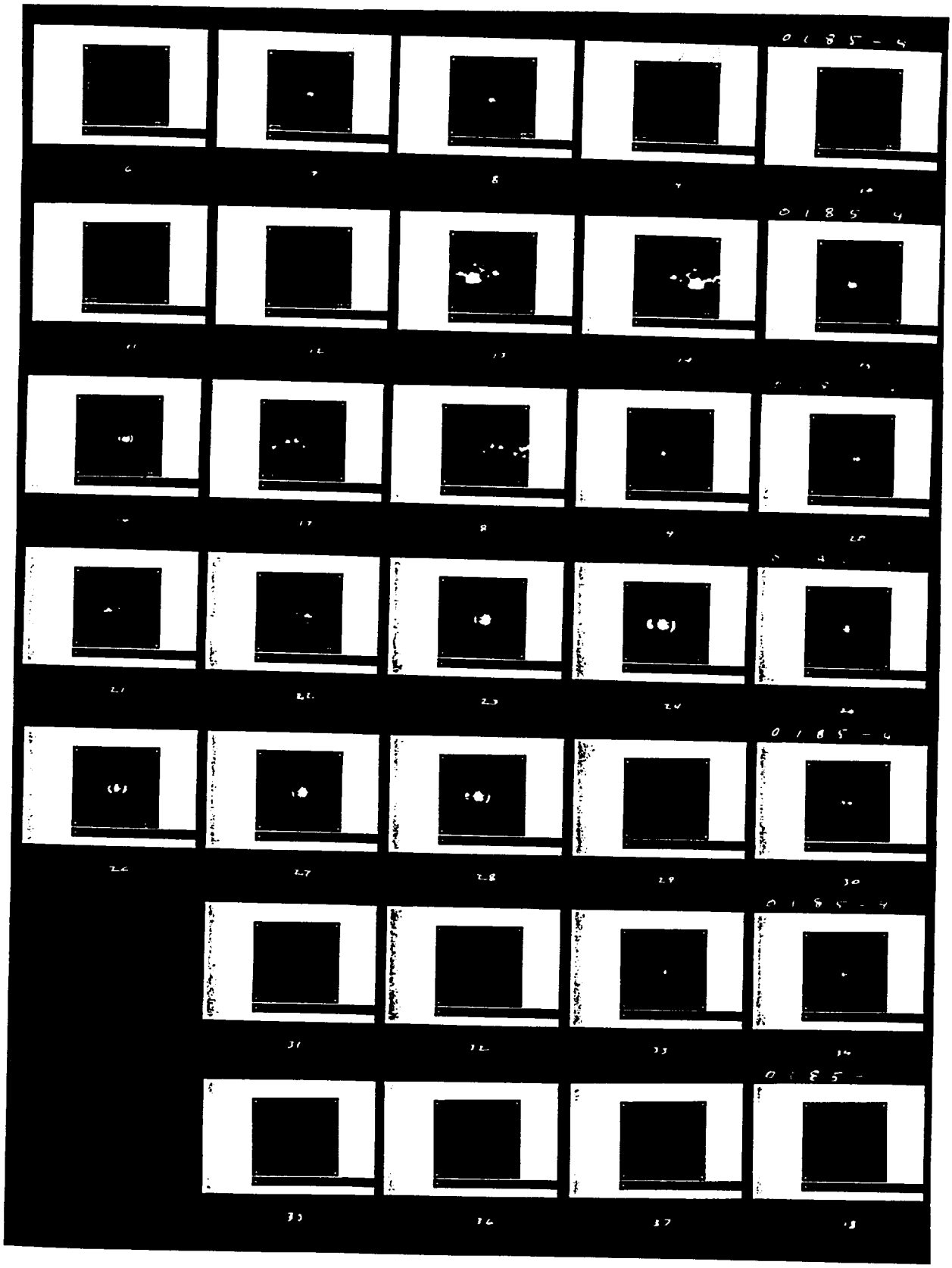


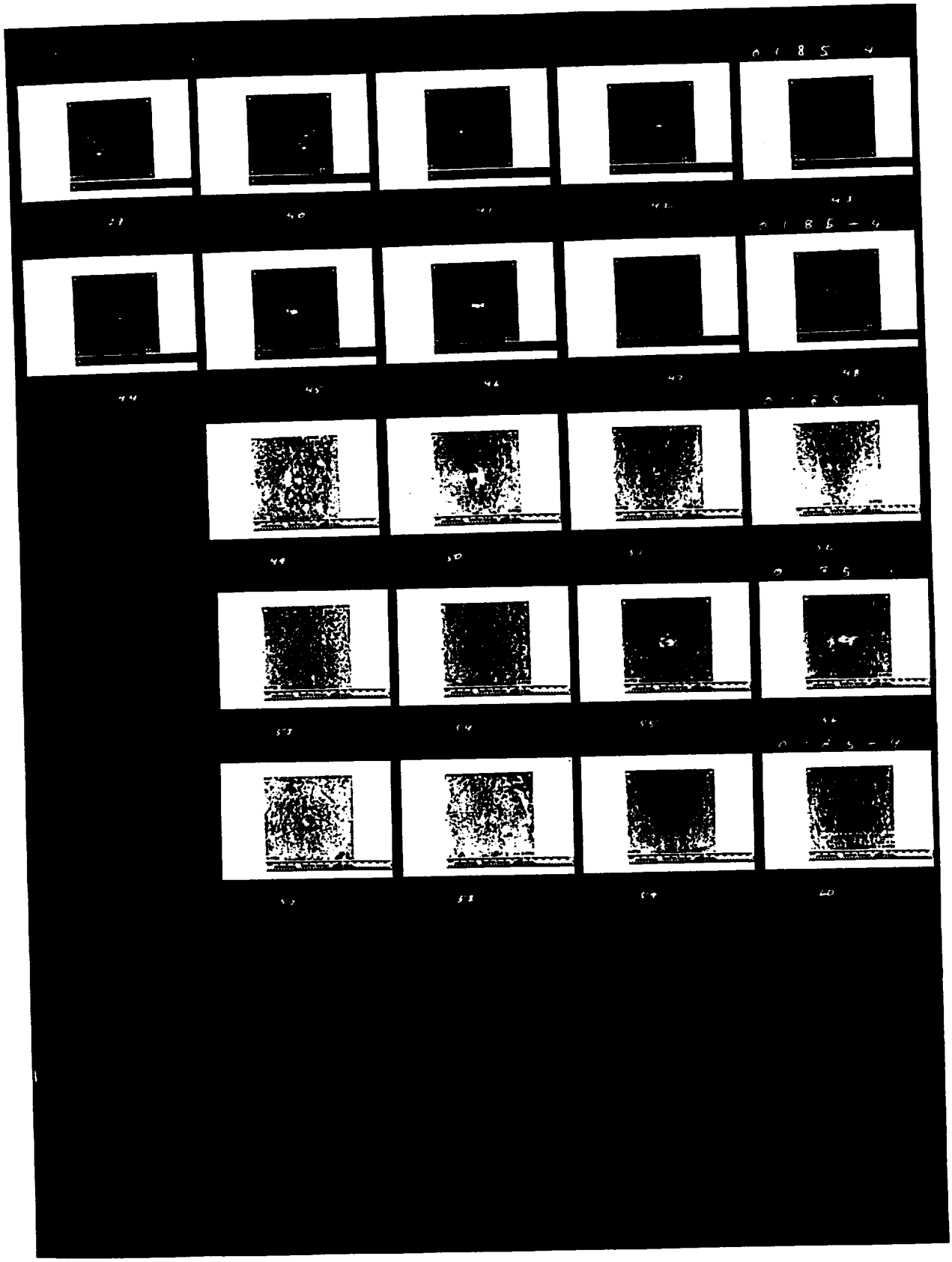

SHOT NO. 41734
TARGET PLATE
PLATE-VIEWING POSITION
SHOT LINE
INTERMEDIATE LAYER
BUMPER
MANY SMALL CRATERS IN THIS REGION
(TRIANGLES DENOTE SHOT LINE)
REAR WALL
DRAWINGS ARE FULL SCALE
V. LARGE BULGE ON REAR
SOME CRACKING OF BULGE
STRONGLY ADHERING SPRAY THIS REGION
ALSO SMALL CRATERS
WITNESS PLATE
NO DAMAGE

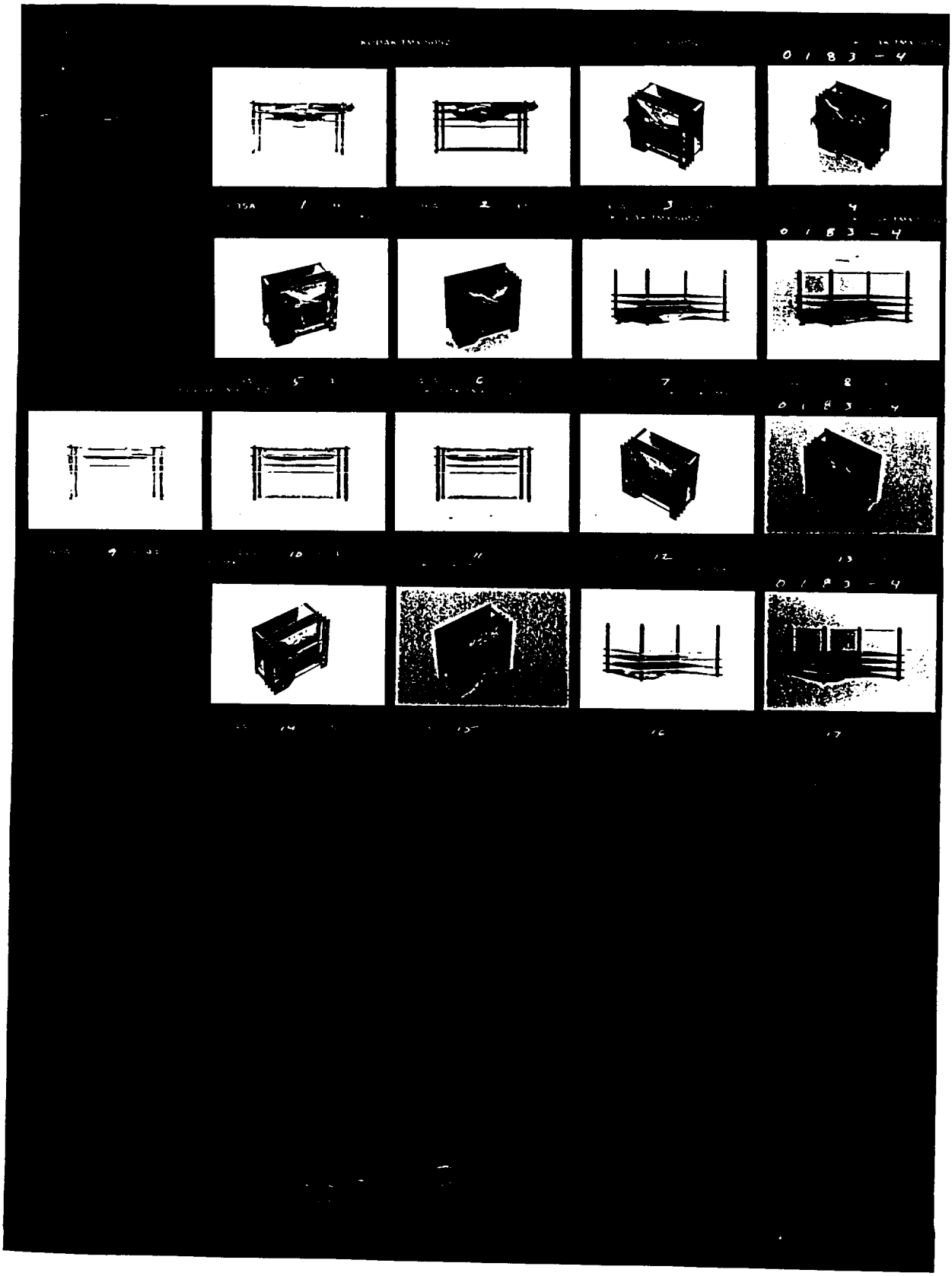


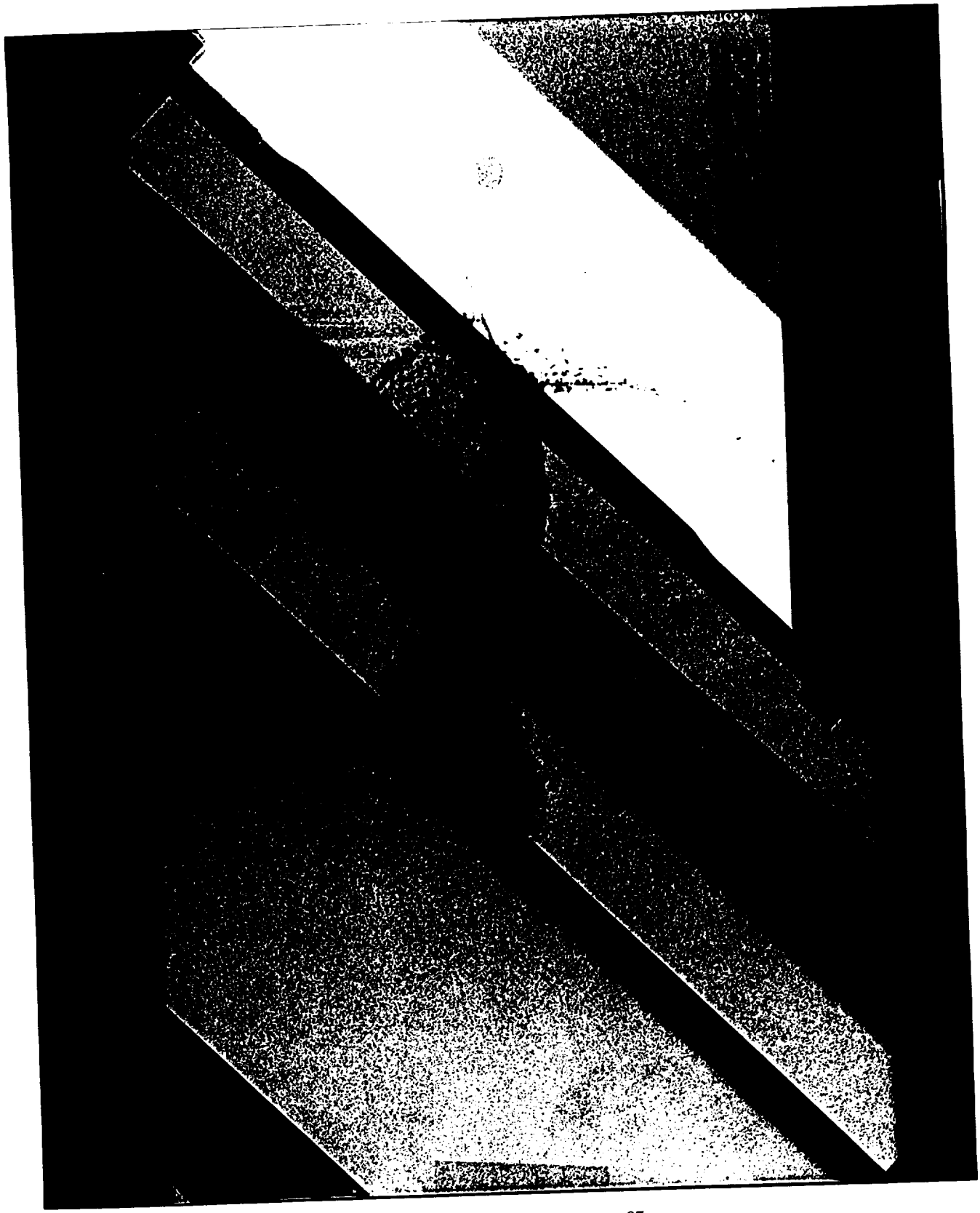


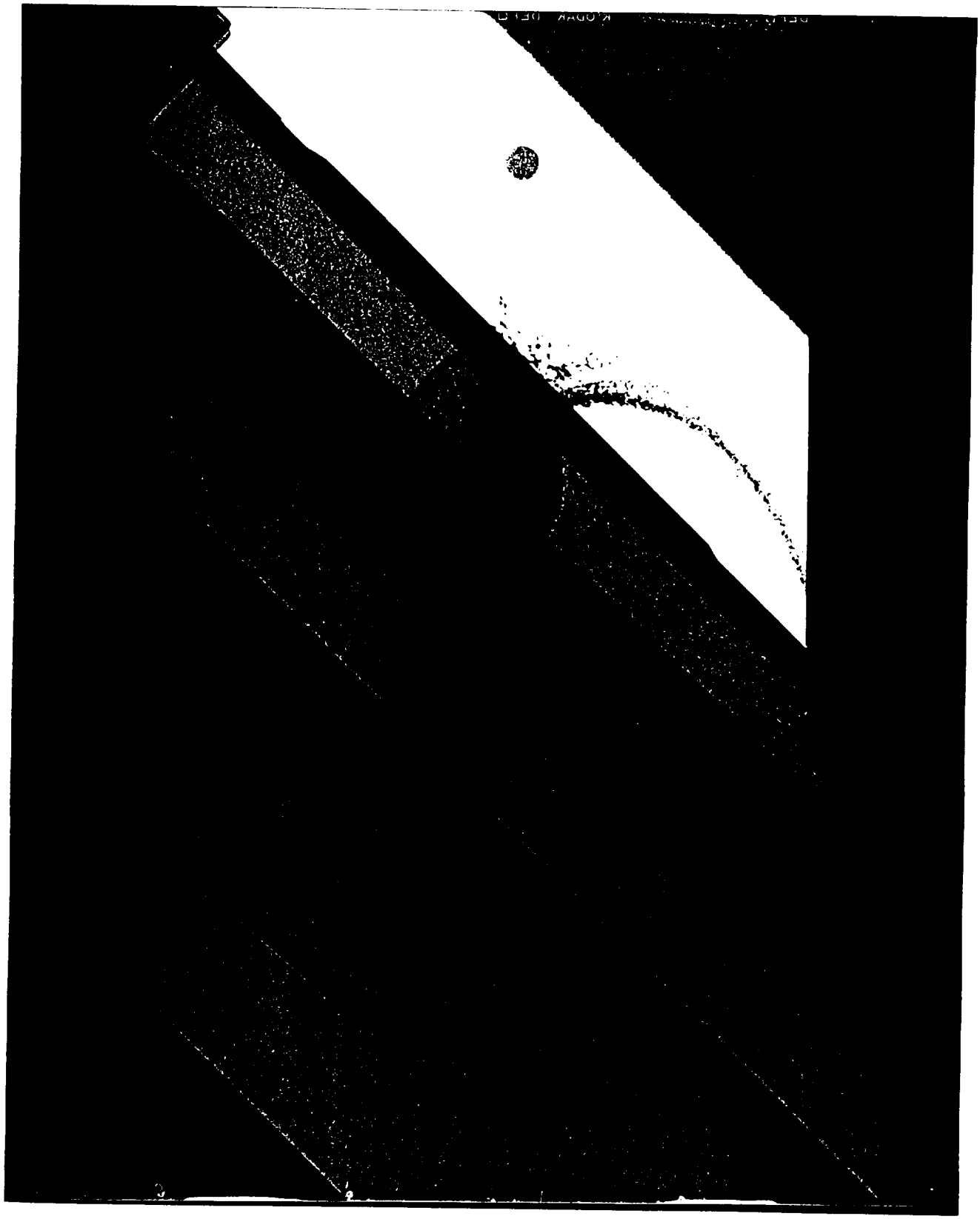


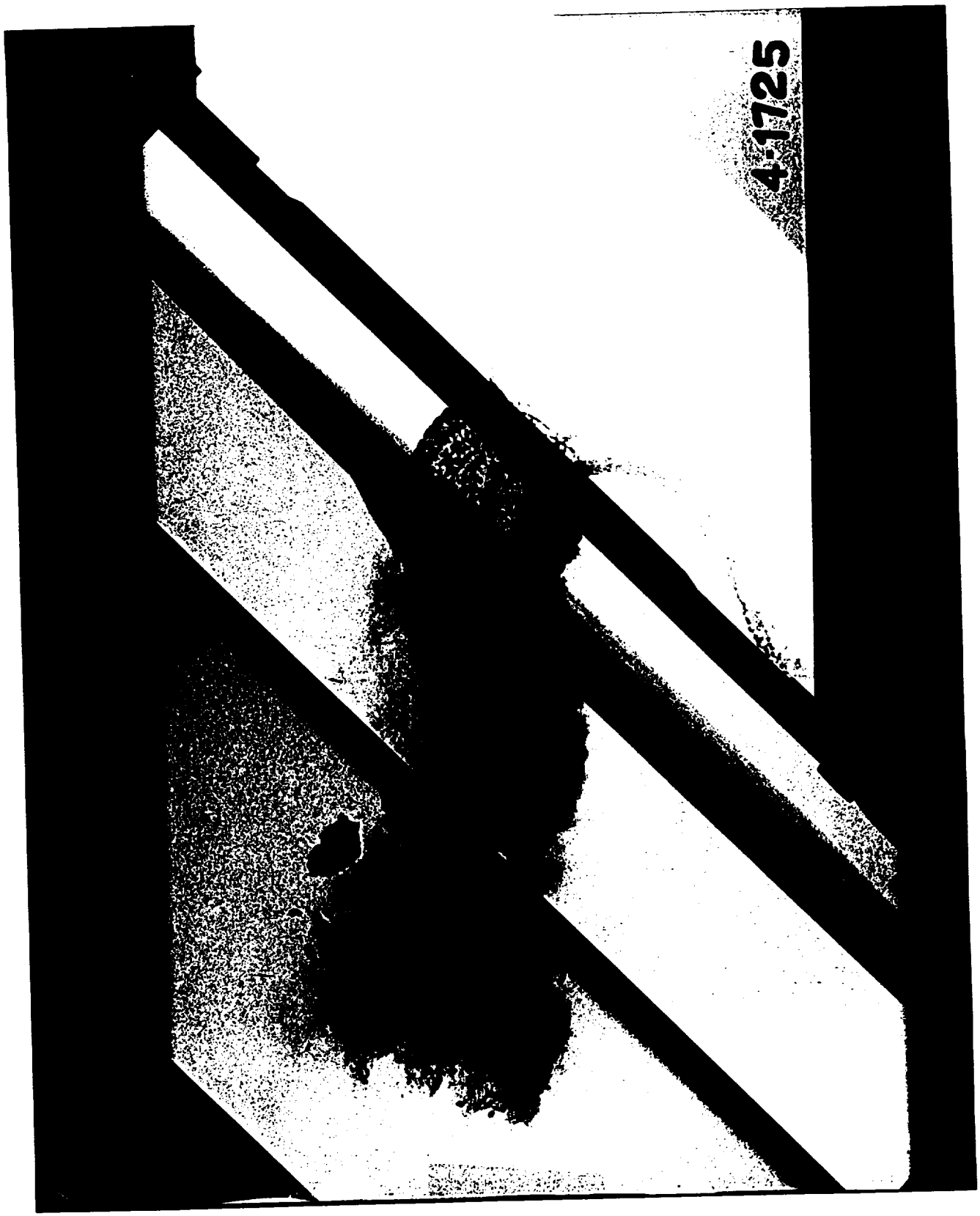








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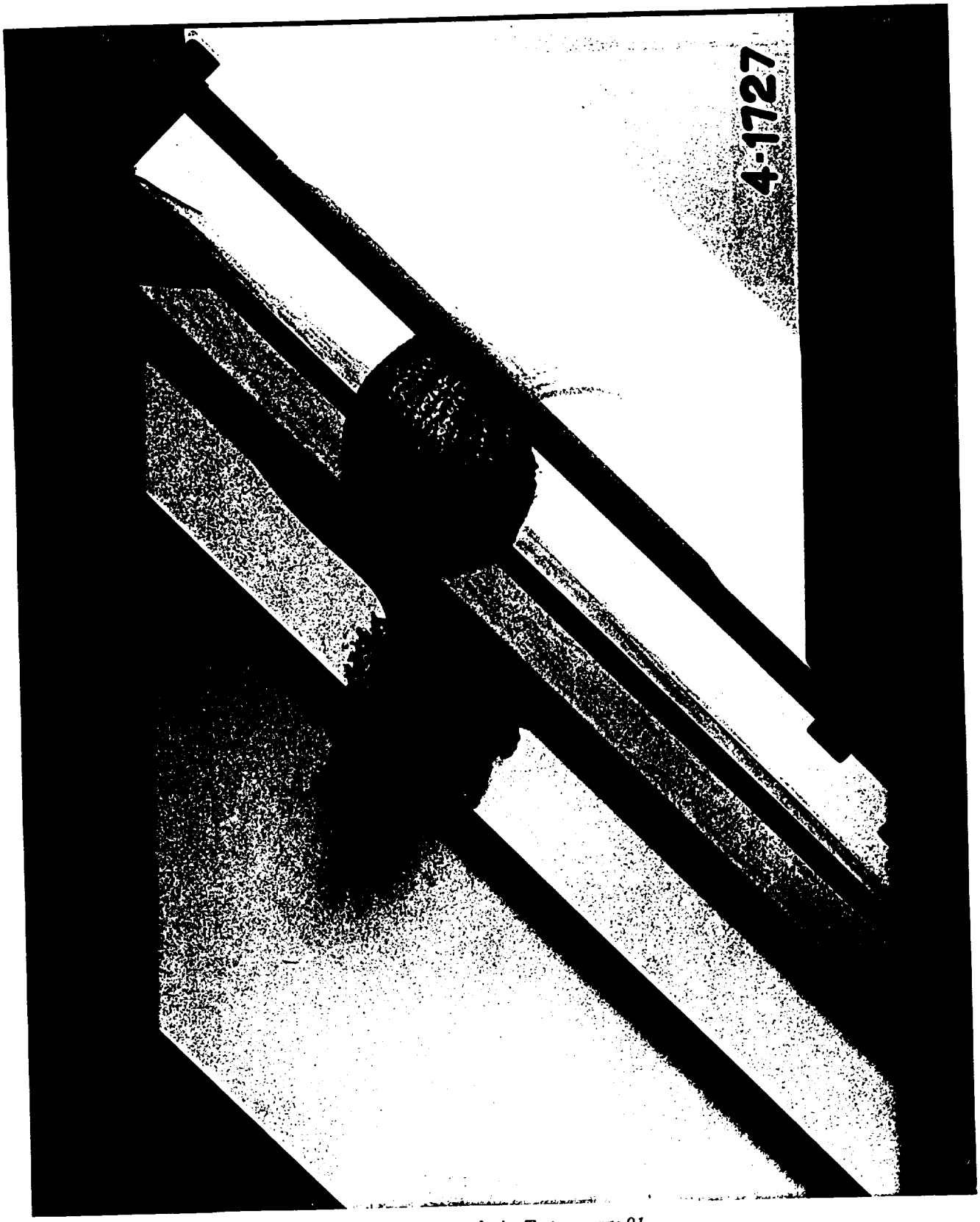
4-1726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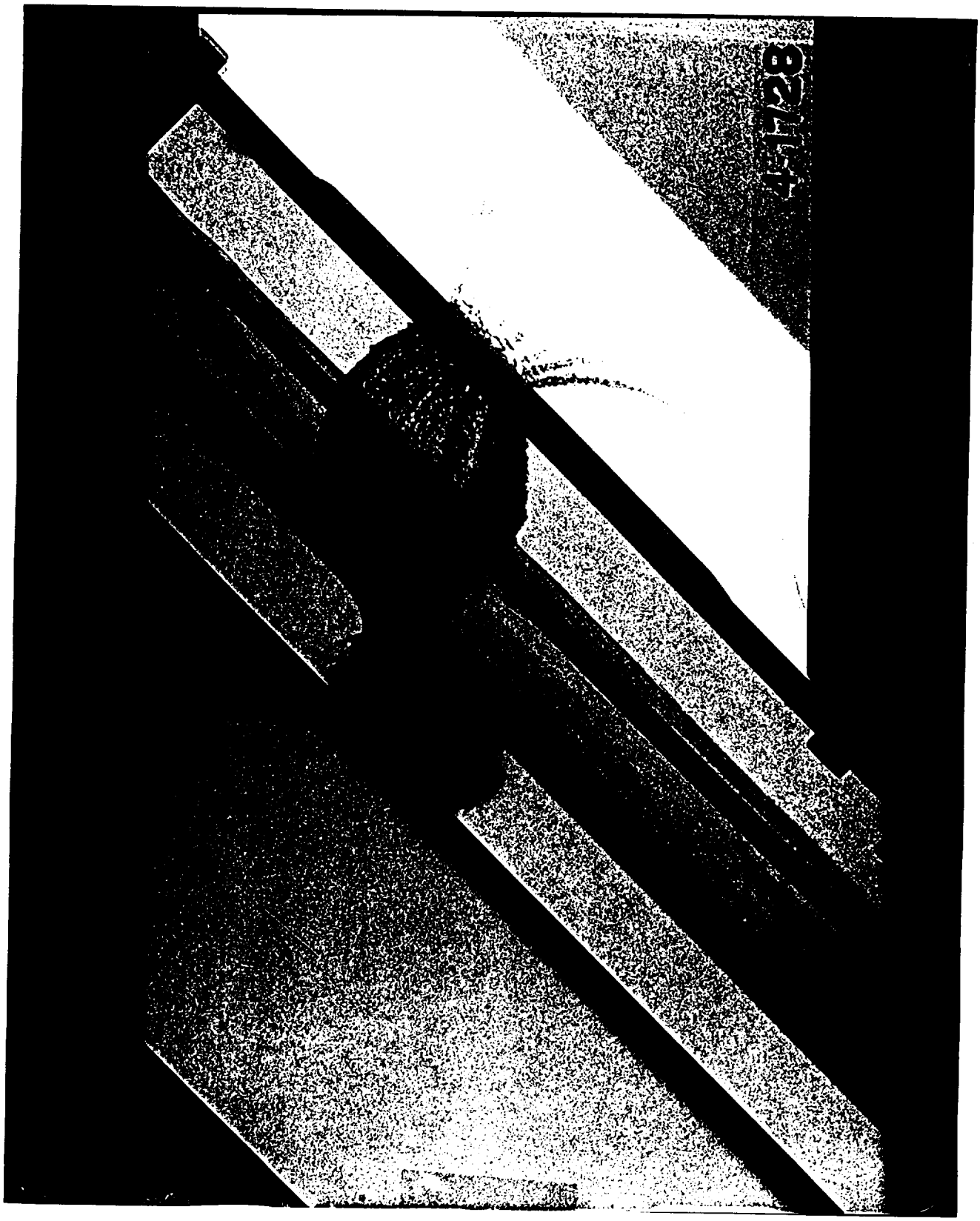
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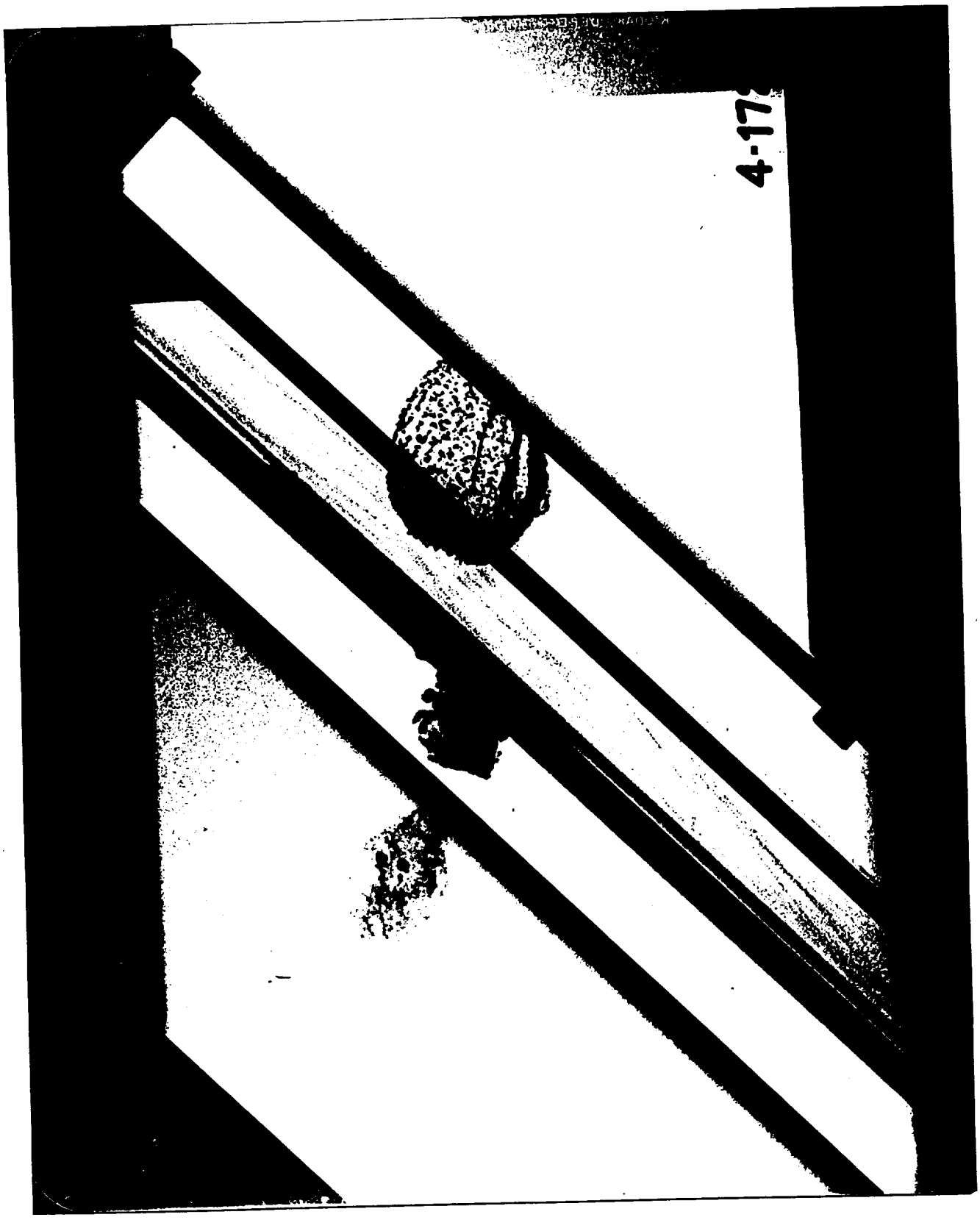
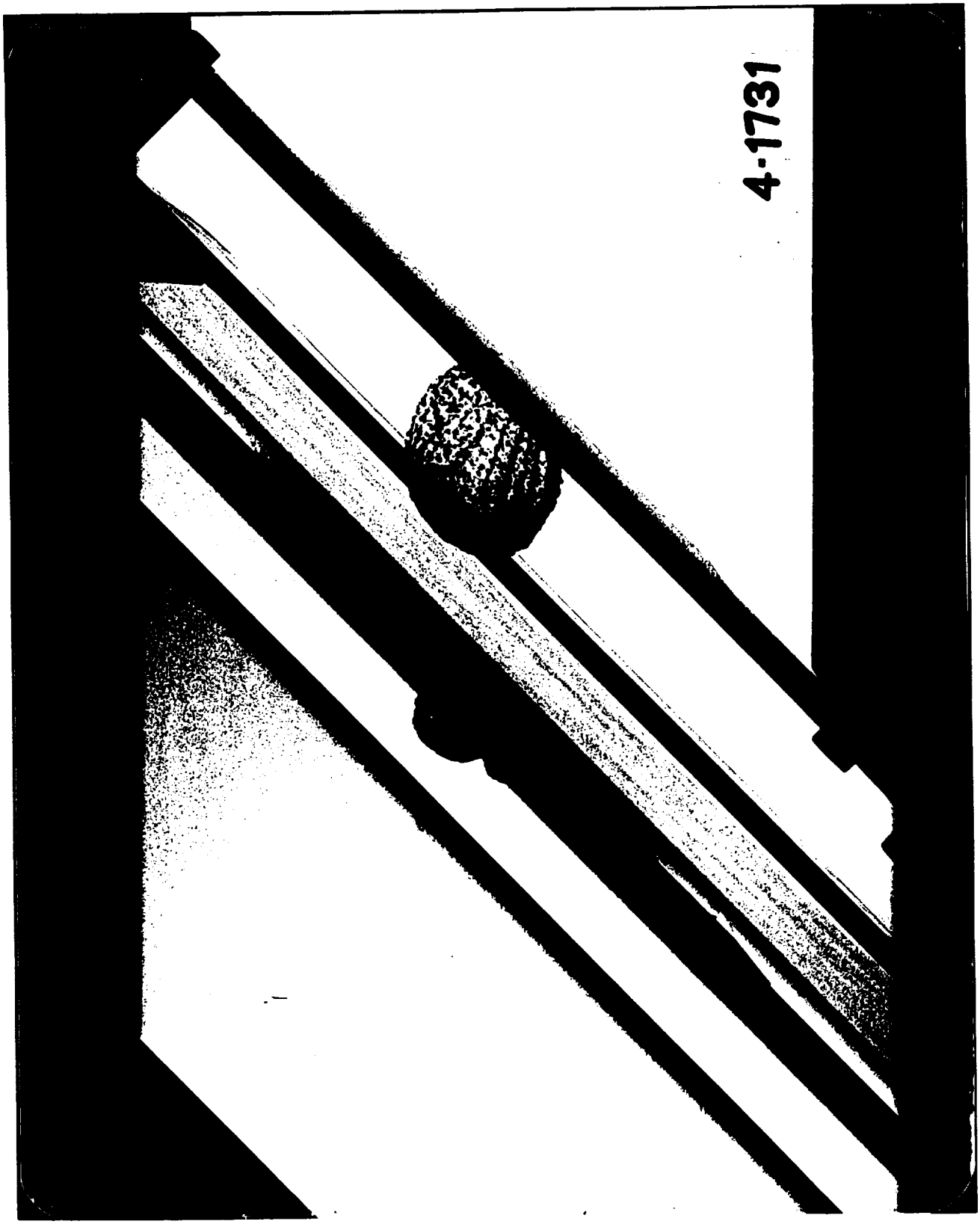

4-17

4-1730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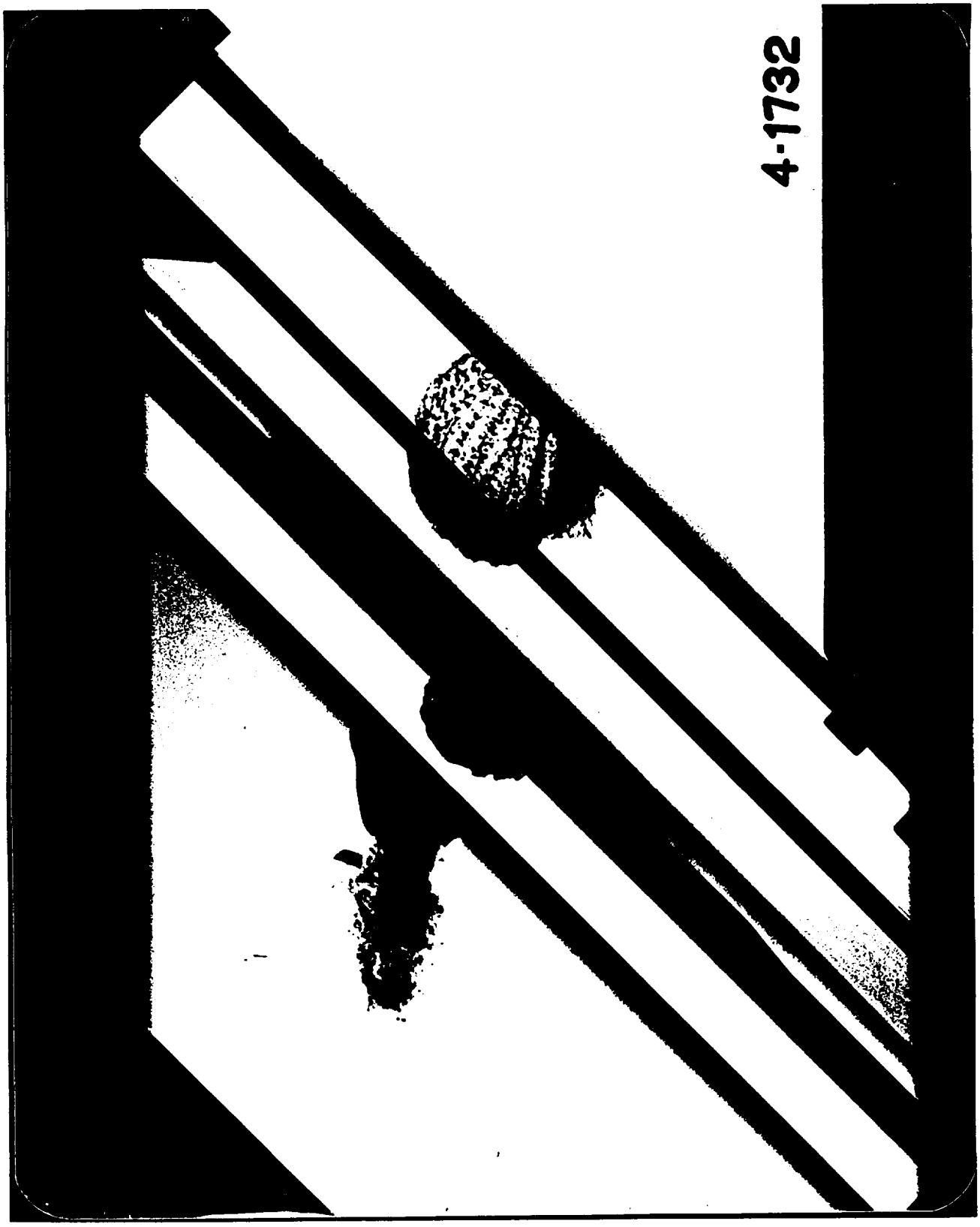
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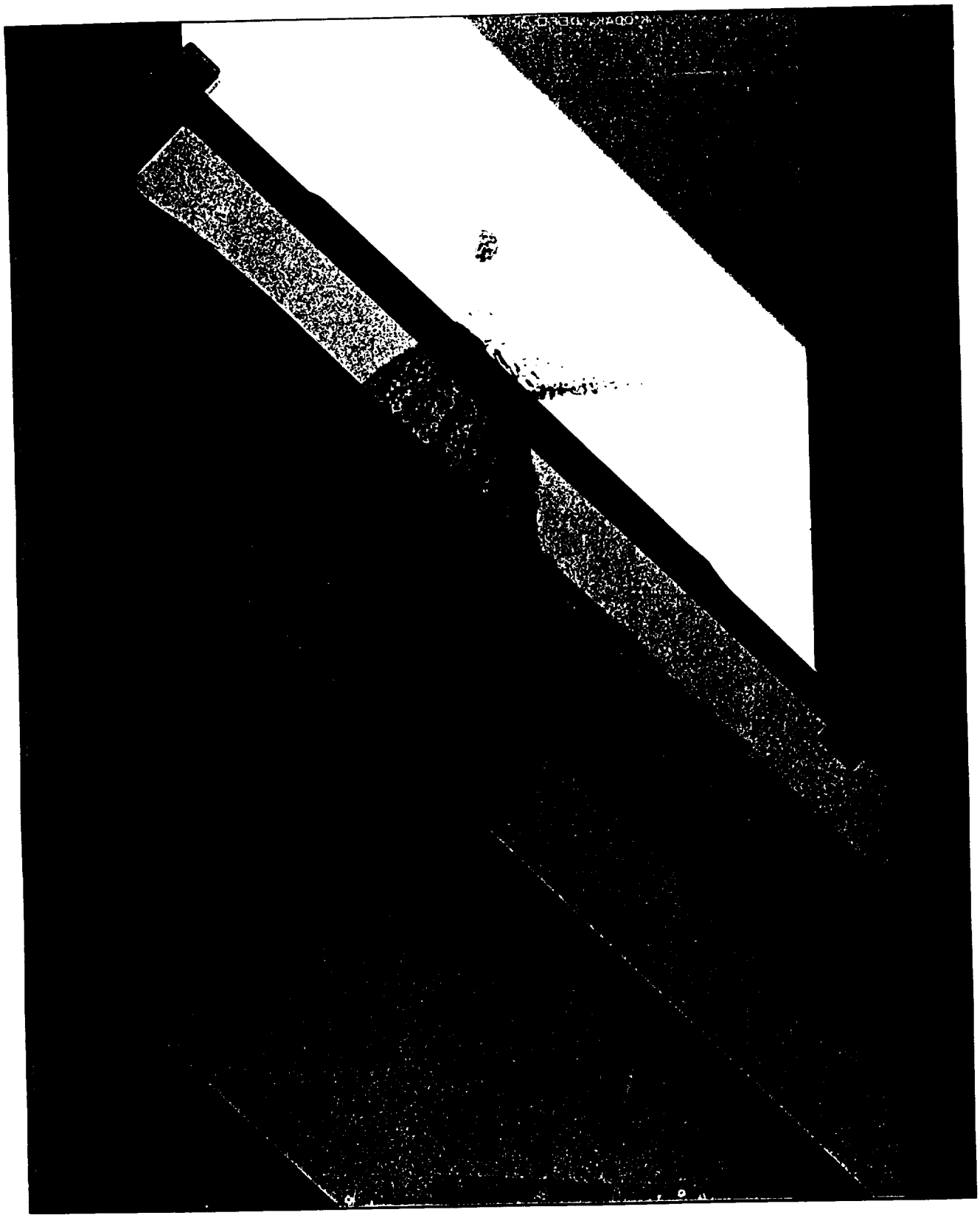

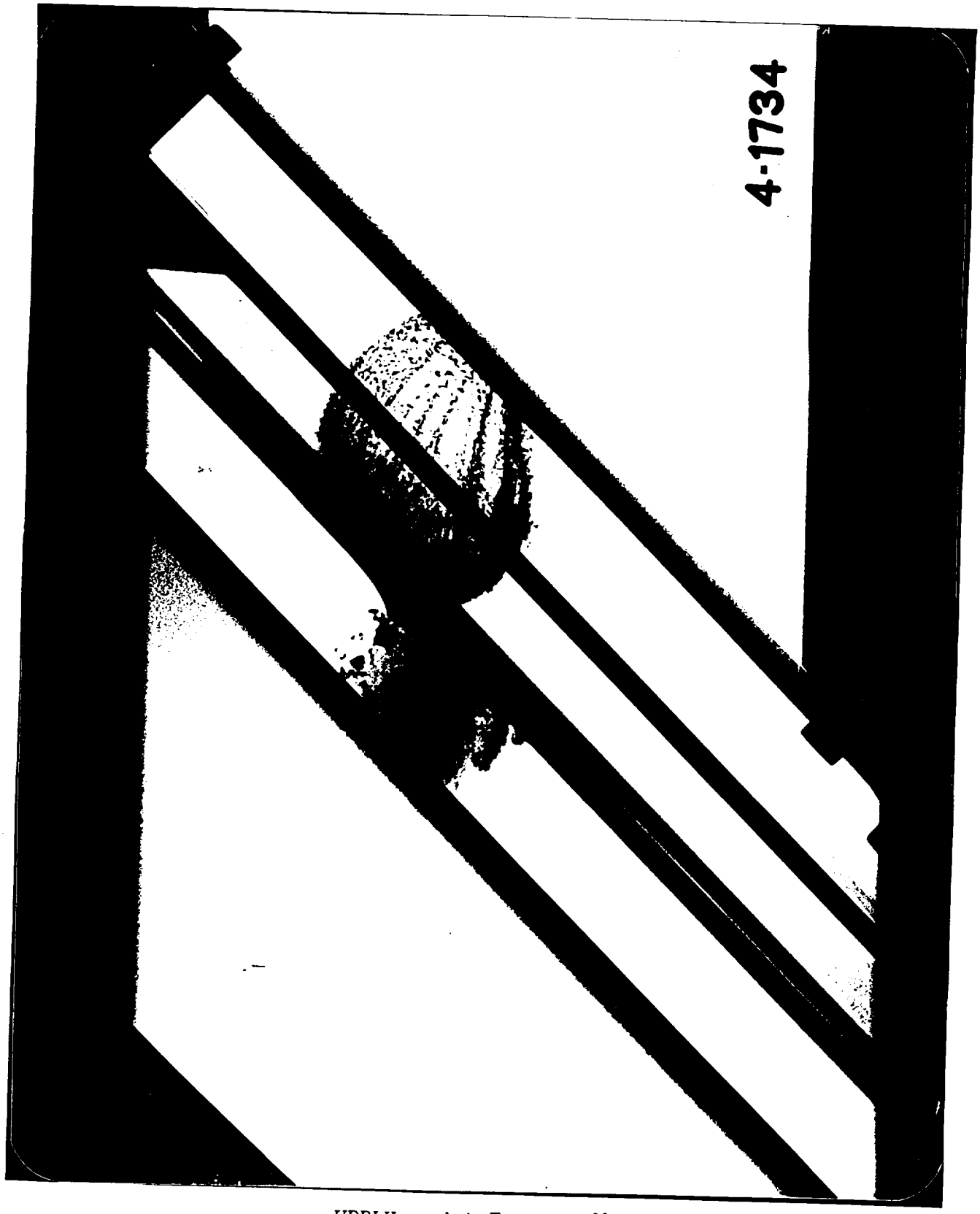
4-1734